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22 August 1960

ACHIEVEMENTS IN OCEANOGRAPHY, No. 1, PROGRESS IN THE STUDY OF THE DEPTHS OF OCEANS

Part I
(of two parts)

\- USSR -

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[Following is the translation of part one of an article by L. A. Zenkevich(editor) entitled "Glubiny Okeyana Kak Ob"yekt Izucheniya" (English version above) in Itogi Nauki (Science Summaries), Moscow, 1959, pages 5-147.]

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PROGRESS IN THE STUDY OF THE DEPTHS OF OCEANS

L. A. Zenkevich (Editor)

ITOGI NAUKI (Science Summaries)
Moscow, 1959

PREFACE

The time is now ripe to summarize our knowledge of the seas and oceans.

During the last ten years, after an interruption of like duration caused by the World War and by the first years of the postwar period, we observe a broad and prolific development of oceanographic research, both in individual countries, as well as in the international plane.

This new upsurge in the development of oceanographic research is produced by several causes: first of all by a wish to exploit the industrial resources of ocean areas which are remote from land, and which, until recently, were almost untouched by research; also by the urgent need to widen the sea and air lanes across the oceans.

Simultaneously, engineering developments have made it possible to apply new study methods, primarily to the ocean floor relief, bottom deposits, biological production processes, ocean

water circulation, etc.

The use of the isotope method in all fields of oceanology, to determine the rate of processes which occur in the oceans, the chronology of past processes and of paleoclimatological and paleiogeographic reconstruction is opening much greater opportunities to the study of the history of the oceans to oceanographers, and thus, at the same time, of the history of the earth's crust in general. The completion of a very large undertaking -- the Third International Geophysical Year (1957/58), whose program encompasses all the oceans, is extremely important to the development of oceanographic research in the most recent times.

The study of the ocean depth zones attracts special attention, and it should prove very productive to many fields of the geological and geographic group of sciences.

It is impossible to compress into one volume the results of research of recent years in all different fields. This collection contains summary works only in geology and partly in marine biology of the ocean depths.

Subsequent collections on the results of oceanographic research, will shed light on achievements in other fields of oceanology.

The article "Pogonophora and Their Distribution" is by the coworker of the Institute of Zoology Acad Sci USSR, A.I. Ivanov. The other articles are by coworkers of the Institute of Oceanography Acad Sc USSR. Ya. A. Birshteyn of Moscow State University is the coauther of two articles.

THE EDITOR

THE OCEAN DEPTHS AS A SUBJECT OF STUDY

by

L. A. Zenkevich, A. P. Lisitsyn and G. B. Udintsev

The problem of studying the ocean depths and of the living organisms living in them has, within the past ten years, assumed a central place in the system og geological and geographic sciences.

This new field of oceanology aims to solve a number of unclarified and debatable problems of the geology and history of the oceans, and then to make a closer approach toward a solution of the general problems of paleogeology, paleogeochemistry, paleogeography, paleoclimatology and paleobiology.

Oceanologists are most interested in problems of the formation of marine deposits, water circulation, and zoogeography of the deep-sea zone, but the study of deep-sea bottom deposits in the oceans leaves all the other problems behind by its importance.

Different new methods were used in the study of ocean depths in recent years.

Plumb lines of different design used in measuring depths until recently, did not make it possible to cover the ocean floor with a dense enough network of probes for technical reasons. Each separate sounding required stopping the vessel for a considerable length of time. Echo sounding devices made it possible

to make an uninterrupted recording of the bottom profile without stopping the ship and to make much more frequent measurements of individual depths without loss of additional time. The first twenty-five years of the use of self-recording sounding devices brought a number of important discoveries. Contrary to the earlier concepts that the ocean bed was a "plain," it was found that it has a very complicated profile. Many underwater mountain ranges were discovered, also deepwater depressions and trenches penetrating the core of the earth 5 to 6 km below the lev l of the ocean bed. A study of the location of these formations at the ocean bottom is of great interest. An accurate bathymetric chart of the world's oceans will alone lead us to the solution of many problems of geotectonics and of the history of the ocean and the earth's crust hidden underneath its surface. We can fully agree with the opinion of Academician A. N. Zavaritskiy that the study of the Pacific Ocean on the widest possible scale is one of the most important problems facing all studies of the earth, and that it is impossible to understand the formation of the earth in general, its continents and seas, without solving the problem of the origin of the Pacific Ocean. This problem, in turn, is inextricably associated with a whole range of the profoundest and most fundamental problems of geophysics, geology and cosmogony. The tasks facing the study of the earth, in the light of research of the outskirts of the Pacific Ocean, said he, are indeed unlimited.

Seismic methods have been used in recent years in marine technique to determine the thickness of deposits on ocean bottoms, and there

is reason to believe that after the removal of a number of difficulties, seismic sounding will not only reveal the over-all thickness of ocean deposits, both porous as well as converted, but will also provide indices of its nature and stratification.

It is hardly possible to overestimate the importance of charting the thickness and nature of the entire mass of bottom deposits of the world's oceans with respect to the problem of the history of the upper strata of the earth's crust. The charting might shed light on the relative age of the oceans and their parts, on paleogeographic reconstruction of oceans and continents, on the theory of drift and the theory of constancy of continents and oceans, on the enigma of Atlantis and Gondwana, on the history of the ocean level, and on much more which remains obscure in the history of the oceans.

Along with this, the inventive ideas of oceanographers try to develop devices for a deep penetration of the mass of bottom deposits. At the present time, hydrostatic and geological suction soil tubes make it possible to take samples of soil several meters in length (on "Vityaz'" soil columns were obtained up to 34 m long). One can hardly doubt that within the near future it will be possible to obtain soil columns in tens of meters and perhaps over 100 m. It is quite possible that drilling of botton deposits will be done with automatic drills placed on the bottom, and this will considerably increase the length of soil monoliths. This method will make it possible to uncover the processes of sedimentation which took place tens of millions years ago in remote parts of oceans, far from shores. Geological, chemical

and biological analyses of these monoliths will uncover changes in the characteristics of the history of the ocean and of its surface, changes in total salinity, salt composition, population composition, temperature regime and climate of the ocean. It is perfectly obvious that all these indices and their system were changing in time and we are now already in possession of very promising methods of their paleochronological recording by the isotope method.

For the purposes mentioned above, the bottom deposits, containing moisture and a relatively undisturbed nature of stratification throughout their immense extent, represent a particularly valuable object of study. Their growth, measured in tens of millions of years, is a sufficiently long time to help us understand many aspects of the processes of diagenesis occurring within the bottom deposits.

Many branches of the geological, geographic, biological and anthropological cycle are experiencing an urgent need of paleoclimatic reconstruction. As a subject of study, the bottom ocean deposits and all that they contain play the main part in climate reconstruction of past geological epochs. A method of reconstruction of paleotemperatures by means of correlating oxygen isotopes has been developed by the Oceanographic Institution in the U.S.A. several years ago. Distinguished for its high accuracy, the method represents a very valuable contribution in this respect.

One of the most important problems of modern physical oceanography - the rate of circulation of deep water masses of the oceans -- is at present being explained in contradictory terms.

German researchers, proceeding on the basis of numerous data, obtained by means of the dynamic method and direct observations, came to the conclusion of high velocity of ocean water circulation, including deep water, approximately within a period of 10 to 15 years. American oceanographers on the other hand, in determining the "age" of individual water masses of the oceans, came to the conclusion that separate ocean regions and their waters have an "age" of hundreds and thousands of years. This problem is at present not only of theoretical, but of a doubly practical interest, since the development of nuclear-atomic industry poses the question of a possibility of using the ocean depths, and particularly deepwater depressions, for the "burial" of industrial atomic waste. However, the circulation of the water masses of the oceans is of importance not only in this respect. In order to understand the phenomena occurring in the oceans on a world scale, it is necessary to know the directions and velocities of the circulation of water masses both in the horizontal and in the vertical direction. Whereas, concerning the surface layer, the nature of circulation is at present well known, concerning deep waters there is still much remaining unclear and undetermined.

The living world which inhabits the ocean depths is a very important subject of study. The distinct peculiarities of deepwater fauna are being explained. These peculiarities find expression primarily in its taxonomic isolation. In recent years abundant material has been collected in the Pacific Ocean, mainly by "Vityaz'" of the

pogonophora group, a new animal group of a subtype or even of a type which does not (as a rule) inhabit small depths. At the present time representatives of this group have likewise been found in the depths of the Atlantic Ocean, but the basic variety (more than twenty forms, kinds, families and orders) was discovered in the northwestern part of the Pacific Ocean. The pogonophora group is very close to, or even a part of the chordate type of animals and possesses features of great antiquity and primitivity.

Danish zoologists recently discovered in material collected by "Galatea" in the equatorial waters of the Pacific Ocean at depths between 3,000 and 4,000 m, specimens of a new and very ancient class of mollusks. In general, deepwater fauna is characterized by considerable antiquity and primitivity, although there are some opinions of it as late fauna. A future study of the material will clarify this issue. The paleotemperature of deep waters of the ocean is of great importance in this connection. The problem of the age of deepwater fauna would become much clearer, if it could be proved that during the course of a series of geological periods, the deepwater zone possessed a low temperature, close to the present (under 2^{0}), and, which is the same thing, that the climatic zones on the terrestrial globe were of long duration and waters in the deeps were also formed in the subpolar regions earlier, as today. The point is that the nature of distribution of deepwater fauna is by no means uniform, and there is reason to assume that it bears the imprint of the orography of the ocean abyss of earlier geological epochs whose age is proportional to their depth. Great interest from this point of

view is presented by the fauna of the ultra-abyssal zone (deeper than 6,000 m) which occupies only 1% of the ocean bottom, which is taxonomically isolated with sufficient clarity from the fauna of the ocean bed at normal depths (5 to 6 Km), and which possesses substantial differences in each oceanic depression. A study of the geological age of this fauna which is scattered among different deepwater depressions, and its comparison with the age of the depressions, can provide very valuable indications of the age of individual parts of the ocean bed and of individual details of its profile. Thus, for example, the age of the meridional oceanic ridges can be compared with the age of isolated deepwater fauna on both sides of these ridges. The age estimate of the degree of taxonomic isolation of deepwater fauna on both sides of the Central American shelf can be compared with that of the shelf itself.

The population of the mass of deep waters, both pelagic and bottom, is a fine, multilateral and powerful indicator of all processes taking place in the ocean depths, of all chemical and physical properties of the water masses, which also takes into account their historical changes.

All what has been said above points to another peculiarity of deepwater research of the ocean, which characterizes oceanography as a whole: the deep interconnection and complexity of the problems posed, of the methods of their solution, and of the use to be made of the results obtained.

Descriptions of the oceans reach back to times of antiquity and

for many centuries they were of a purely geographic nature. Early in the 19th century scientists became interested also in the underwater world of the ocean, but it was not until the English expedition on the ship "Challenger" (1872 to 1876) that success was achieved in penetrating the secrets of the ocean depths. During the post-challenger period a number of expeditions were organized for the purpose of studying the floor of the ocean, but the greatest depths (over 5,000 m) were hardly touched by observations.

The last ten years were very successful in the study of the deep-water zone of the oceans. A number of deepwater expeditions working almost simultaneously, and the new methods used by them immediately showed the enormous value of the ocean depths as a subject of study; the ocean depths were as if "discovered anew" by these investigations.

During the World War II period the techniques of oceanographic research made a great forward leap in connection with the needs of navies. A number of completely new devices made their appearance, and many devices which existed before were radically improved. Thus, for example, there appeared new radio engineering means of coordination: loran, shoran, the electronic position locator and radar which made it possible to considerably increase the accuracy of plotting the position of a ship; thermo-bathygraphs, automatic geomagnetic current recorders which made it possible to determine surface currents while the ship was in motion; automatic salinity recorders, hydro-acoustics locators, and many other devices. Ultrasonic sounding devices were radically improved and their power and accuracy were greatly increased.

New scientific and engineering equipment of the expedition ships made it possible to undertake around-the-world expeditions at a new and qualitatively higher level. Along with this, there were much higher practical demands, in particular on the part of navigation, the fishing industry, and naval forces. Wide conquest of the world's oceans is going on at the present time, and not merely of their surface, but also of the depths. Man's economic activities are no longer confined to the conquest of inland and neighboring seas, but is spreading more and more to the central areas of oceans. This requires the most serious and multilateral study of the nature of the oceans.

During the past ten years three major foreign scientific around-the-world voyages have been completed: the Swedish expedition of 1947 and 1948 on the "Albatross," the Danish of 1950-1952 on the "Galatea," and the English of 1950-1952 on the "Challenger." Numerous (over 25 major voyages) and prolific voyages were completed by the Soviet scientific-research expedition ship "Vityaz'" (1949 to 1958).

Chronologically, the Swedish expedition on the "Albatross" was the first (Fig. 1). It was organized by the Goteborg Oceanographic Institute mainly by private contributions. The expedition was carried out on a ship of a private shipbuilding concern, the sailing motor schooner "Albatross," with a displacement of 1,450 tons. The holds and compartments of the "Albatross" were converted to laboratories and living quarters for 10 to 12 scientists. Since the expedition was going to the tropics, the ship was equipped with air-conditioning and with special refrigeration to preserve specimens. The expedition was planned for

work mostly at great ocean depths and for this purpose it was equipped with a number of new devices. We must mention a new powerful electric hoist for lowering soil probes and trawls and a heavy suction tube designed by Kullenberg for drawing columns of sea deposits 15 to 20 m long. The expedition possessed a new automatic sounding device for work at depths greater than 7,000 m, as well as a seismic apparatus of the Weibl system.

The famous Swedish oceanographer Hans Pettersson was chief of the expedition. Commanding the ship was Captain N. Krafft. Taking part in the expedition were professors Weibl, Kullenberg, Orlov, Kozny, Nibelin and others.

The main purpose of the "Albatross" expedition was to obtain long columns of sea sediment in the equatorial region, in the zone of convergence and divergence. In addition one of the tasks of the expedition was to study the relief of the ocean floor by means of an automatic sounding device along the entire itinerary, special hydro-optical research, hydrochemical observations, and in particular determination of uranium and radium content in sea water. Finally, the expedition was to investigate the abyssal fauna in the North Atlantic.

The "Albatross" sailed from Goteborg on July 4, 1947, was at sea for a period of 15 months, and returned to Goteborg on October 3, 1948. The itinerary of the expedition (see Fig. 5) was as follows: Goteborg -- Martinique -- Panama -- Galapagos Islands -- Tahiti -- Hawaii -- Philippines -- Java -- Cocos Islands -- Ceylon -- Seychelles Islands -- Aden -- Suez Canal -- Gibraltar -- Cape Verde Islands -- Fernando

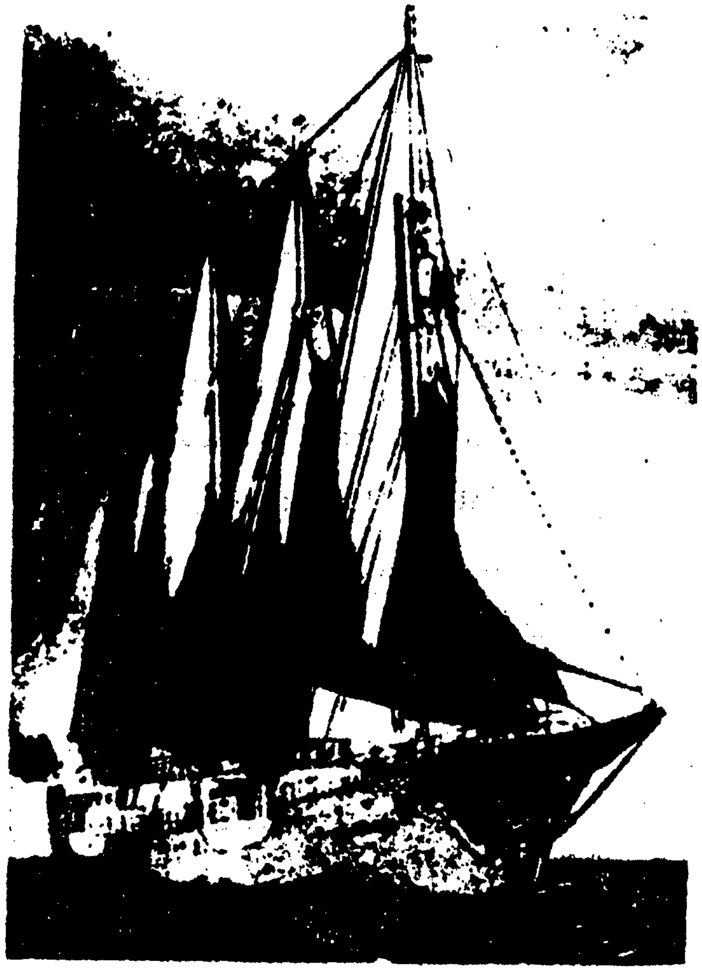

Fig. 1. "Albatross" -- ship of the Swedish around the world expedition of 1947-1948.

de Noronha -- West Indies -- Bermuda Islands -- Goteborg.

When the expedition was completed, the material gathered was processed by the entire staff of the Goteborg Oceanographic Institute. In addition, some material was turned over to other scientific institu-

tions in Sweden, as well as England, U.S.A., West Germany and Austria. It was hoped that processing of the material collected by the expedition would take two to three years. However, it is not finished to this day, and will probably continue for several more years. Nevertheless, numerous articles are already appearing in print, setting forth the basic scientific achievements of the "Albatross" expedition, as well as separate volumes of reports on completed sections.

We cite the basic scientific results of the expedition.

1. The first detailed data were obtained on the complex differentiation of the ocean floor at depths between 5,000 and 7,000 m. The information about the existence of a complex half relief floor of the ocean is of particular interest.

2. A preliminary lithological study of long columns of soil has been made, their total length reaches 1,600 m (200 columns); the presence of sandy particles has been found at great depths and at an immense distance from the source of their entry. This is associated with the transmission of sands by turbulent currents, and with various processes of authigenic mineral formation. New and interesting data were also obtained on underwater erosion, as well as on the chemical interaction between sediments and bottom waters.

3. A study of the microflora and microfauna has been made, approximately every 10 cm of the long columns. The results of the investigations, conducted by Pledger, Schott, Riedel, Ovey and Wiseman, and by other researchers, indicate that in the geological past there have been substantial changes of physico-geographical conditions in the equatorial

region of the oceans. In columns taken in the zones of convergence and divergence, there is a particularly noticeable sediment stratification due to the apperrance of numerous streaks of foraminiferous sand. Regions were also discovered where to a depth of nearly 15 m. from the bottom surface sediments are not stratified and represented only by red clays and radiolarian silt. Taking into account the low sedimentation rate in these regions, H. Petterson believes that red clay began forming between 15 and 30 million years ago, i.e. as early as the Tertiary period.

4. Investigations were made of the mineralogical and granulometric structure of columns, as a result of which numerous horizons of volcanic ash were discovered which are associated with early historical and prehistorical eruptions.

5. Investigations were made in the area of radioactivity of sea water and sediments; previously known information was enlarged upon concerning the practically constant uranium content in sea water -- (1.3×10^{-7} g U/cm^{3}), and concerning radium content of sea water. The complex distribution of radium along the vertical in columns has been clarified, on the basis of which it can be assumed that radium migrates in a vertical direction, and for this reason direct determination of radium is unsuitable for an explanation of the absolute age of soil. This is especially important in connection with the fact that American researchers widely use the Arry method in determining the absolute age of sediments according to radium content. In order to determine their absolute age in the light of results obtained, the thorium and

ionium methods are now used.

6. On the basis of the study of microflora and microfauna, and also by means of radioactive measurements, it was ascertained that the sedimentation rate in the Pacific Ocean fluctuates from 1 mm per 1,000 years for red clays to 15 to 25 mm per 1,000 years for calciferous silt. In the Mediterranean the sedimentation rate has been calculated to be 100 mm and more per 1,000 years. The radiocarbon method was used in these determinations in particular.

7. Seismic studies according to the Veibl method made it possible to determine the maximum thickness of sediments, equal to 3,500 m. in the Eastern Atlantic between Madeira and the Middle Atlantic Range. In the open parts of the Pacific and Indian Ocean the reflecting surface is located at depths of several hundred meters below the floor surface. It is possible that the reflecting surface represents an interlayer of lava. This conclusion was confirmed by subsequent data of American and British expeditions.

8. The first attempts to measure the geothermic gradient on the ocean floor undertaken by the expedition provided an idea of its magnitude. In the central part of the Pacific Ocean near the Equator, at a depth of 4,[illegible]0 m, the temperature increases by 1° in penetrating the sediment 21 m., in the western part of the Pacific Ocean, at a depth of 5,300 m the increase of temperature of 1° is observed at a depth of 26 m. In the Indian Ocean, between the Cocos Islands and Christmas Island, the gradient reaches the immense magnitude of 4 m. A conclusion has been reached that the thermal current at the ocean floor is almost as

intensive as on the continents. A particularly high gradient has been observed in the Indian Ocean, similar to the gradients close to volcanoes and solfatara.

9. Biological studies, made toward the end of the voyage in the Atlantic, indicate that there is life at depths up to 7,600 m. The trawling depth reached by "Albatross" exceeded the record depth of trawling of 6,000 m set by the expedition of the Prince of Monaco, by 1,600 m. It is interesting to note in this connection that Soviet investigators carried out trawls at depths in excess of 8,000 as early as 1949.

10. Hydro-optical investigations by means of the tyndallmetric method made it possible to provide quantitative determinations of suspended matter in the mass of ocean waters and to determine the presence of numerous clouds of mud in the oceans.

Within ten months after the completion of the "Albatross" voyage, the ship "Vityaz'" (Fig. 2) began its investigation of the Far Eastern waters of the USSR and of the adjacent parts of the Pacific Ocean; it is a Soviet research ship. There is a number of substantial differences in the organization of expeditionary investigations conducted by this ship and by the three above mentioned foreign expeditions ("Albatross," "Galatea" and "Challenger"). The three foreign expeditions were of an episodic nature; they completed around-the-world voyages, principally in the equatorial belt, and the ships completing these voyages were not expressly made for expeditions, but were acquired for a relatively short period (one and a half to two years), and were only adapted to oceanic investigation. The ships as such were relatively small in size, with a displacement

of 1,000 to 1,500 tons, with small quarters for laboratories and limited scientific personnel. For this reason they did not have an opportunity to conduct complex oceanographic investigations, and chiefly worked in any single field. Thus, for example, "Galatea" studied mostly the animal and bacterial population of the ocean bed and of deepwater trenches. The "Vityaz'" is a much larger-sized ship. Her displacement is 5,500 tons, the scientific personnel is between 60 and 65 persons, and there are 14 well-equipped laboratories. This makes it possible to conduct simultaneous complex work in all branches of oceanography, with the deck and laboratory equipment being adapted to this purpose. Although some individual voyages of the "Vityaz'" are undertaken for special purposes, in general, however, the investigations are of a wide complex nature.

The specially equipped expedition ship "Vityaz'" belongs to the Institute of Oceanology Ac Sci USSR has been engaged in uninterrupted work since 1949 and will continue the work in the future. This will make it possible continually to improve the laboratory ship in all the details of the complicated and many-sided methods of marine work, and to maintain succession both in this regard, as well as with regard to the problems being developed and investigating habits of the numerous personnel of co-workers and officers of the "Vityaz'." The Institute and its floating research base form a single unit, and their simultaneous activity will assure Soviet oceanography continued success.

There are additional substantial considerations distinguishing the work of the three foreign expeditions from the work of "Vityaz'." Until the present time, the latter conducted investigations within a relati-

Fig. 2. Soviet research ship "Vityaz'."

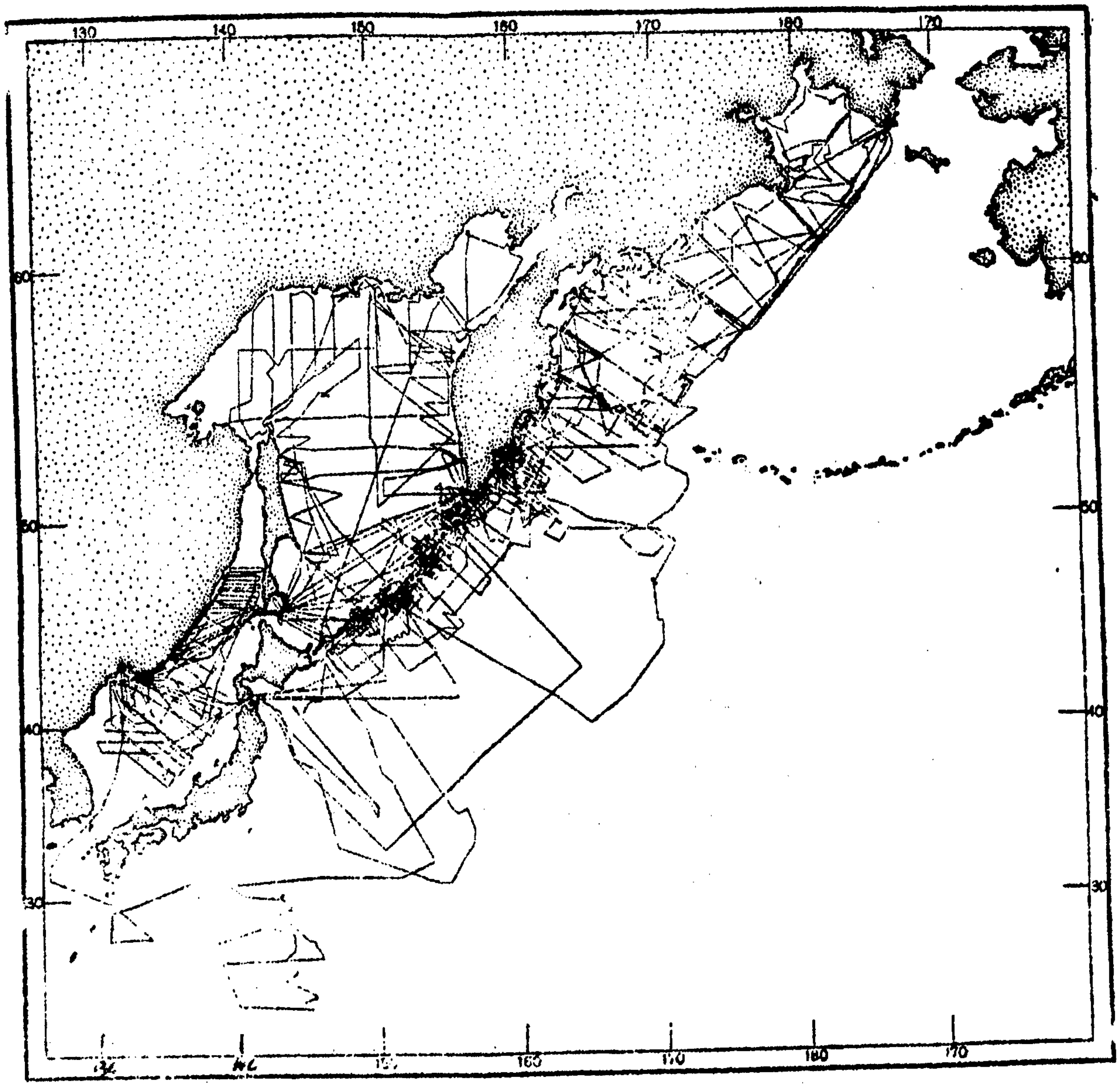

Fig. 3. Routes of the "Vityaz'"
expeditions, 1949 - 1955.

vely small area of the ocean: in the Sea of Japan, Okhotsk and Bering, and in the adjacent part of the Pacific Ocean, comprising a total area of about 7 million km^2. During that time "Vityaz'" completed 25 separate voyages in the Far East (Fig. 3). During the period of the International Geophysical Year the ship completed several additional major voyages encompassing the entire Pacific Ocean within the limits of the Northern Hemisphere, and one of voyages carried the work of the "Vityaz'" in two meridional cuts far south, to New Zealand.

The "Vityaz'" investigations have contributed much new material to the study of the Pacific Ocean depths. Great care has been taken to describe the relief of the northwestern part of the Pacific Ocean, and particularly of the Kurile-Kamchatka trench and of the underwater part of the entire Kurile Island chain. Huge underwater mountains were discovered and described: the "Vityaz'" range, the Academician Shirshov range, and the North-Hawaiian range. A very large number of long (up to 34 m) columns were obtained of bottom sediments and determinations were made of the total thickness of porous deposits of the bottom and of their chemical characteristics.

The study of the deepwater zone of the northwestern part of the Pacific Ocean uncovered new deepwater fauna with hundreds of new forms and a large number of new kinds, families, and categories of a higher system.

Soviet biologists produced a new chart of vertical zonality in the distribution of oceanic fauna, a new deep ultra-abyssal zone has been isolated and substantiated (over 6,000 m) -- the zone of oceanic depressions with its separate characteristic living world. The first

diagram of a geographic zoning of the deepwater fauna of the oceans was made, explaining its numerous ecological peculiarities.

Hydrochemical and hydrological investigations of ocean depths also uncovered a lot of new matter.

The University of Copenhagen was sponsor of the "Galatea" expedition (Fig. 4). A navy frigate was used, which was specially refitted for investigation work. The "Galatea's" displacement was 1,630 tons and the speed was 16 knots. The ship was equipped with one large laboratory and living quarters for 12 to 14 scientific workers. The equipment included a modern automatic sounding device up to 10,000 m, a deepwater trawling hoist obtained from the "Albatross," refrigerators to preserve specimens, special equipment for geomagnatic research at great depths, trawls and Petersen dredges.

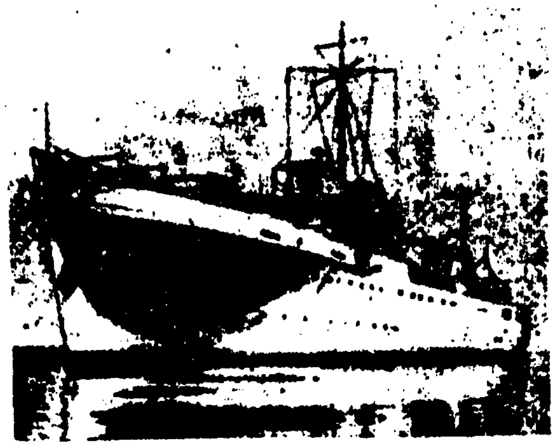

Fig. 4. The ship of the Danish round the world expedition "Galatea," 1950 - 1952.

Professor Anton Bruun of the University of Copenhagen was scientific director of the expedition. Also taking part in the expedition were Professors Spärck, Hagen, Wolff, Madsen, a number of Danish and several foreign scholars, particularly the microbiologist Zobell (USA), Kullenberg (Sweden), Davis (South Africa), as well as zoologists from India, Siam and the Philippines.

The main purpose of the expedition was to study life at abyssal depths, and especially in deepwater ocean trenches. The plans called for investigation by means of deepwater trawling, taking samples from the floor and soil tubes of comparatively short length, as well as sampling water. In addition, the ocean floor relief was to be studied throughout the whole route of the expedition, with more detailed measurements taken in deepwater trenches. Magnetometric observations were a separate task of the "Galatea" expedition.

The "Galatea" left Copenhagen on October 15, 1950 and was at sea for 21 months, returning to Copenhagen on July 17, 1952. The itinerary of the expedition (Fig. 5) was as follows: Copenhagen -- English Channel -- Bay of Biscay -- Coast of West Africa -- Cape Town -- Coast of East Africa -- Madagascar -- Mombassa -- Seychelles Islands -- Ceylon -- Calcutta -- Nicobar -- Singapore -- Bangkok -- Philippines -- Indonesia -- New Guinea -- Solomon Islands -- eastern and southern Australia -- Tasmania -- Wellington -

Campbell -- Auckland -- Kermadek -- Tonga -- Samoa -- Hawaii -- California -- Mexico -- Panama -- West Indies -- Azores -- English Channel -- Copenhagen.

The material gathered by the expedition was processed after its completion. A number of articles and books explaining the work of the expedition were published, also the second volume of the Proceedings of the Expedition containing articles with the results of fauna collecting from depths greater than 6,000 m. The following are the most noteworthy results of the "Galatea" expedition.

The expedition conducted detailed investigations of the floor relief at great depths. Work in deepwater ocean trenches proved particularly interesting. Such, for example, are data concerning the underwater relief of the Philippine, Java, Solomons, Tonga and Kermadek trenches. The work of the "Galatea" disclosed the step-like nature of the slopes of deepwater trenches and a narrowness of their deep parts. In should be noted that the "Galatea" took measurements of the depth of the Philippine trench producing a very critical appraisal of earlier data concerning the maximum depth of this trench. Instead of the earlier known "Cape Johnson" depth (10,540 m) the "Galatea" measured 10,082 m, and the maximum depth of 10,265 m found by the "Galatea" should be regarded as the maximum depth of the Philippine trench.

The most interesting results of the expedition are in the field of biology. The expedition discovered a large number of new forms of deepwater animals, conducted successful trawling and dredging at the greatest depths of the Philippine trench and determined the existence of a specific abyssal fauna. Like Soviet investigators, A. Bruun believes that it is possible to set apart a separate zone, deeper than 6,000 m; he calls it the hading zone. In addition, bacteria were obtained from maximum ocean depths, belonging to the barophile type, i.e., adapted to life under great pressure, which perish when pressure is reduced. Investigations of the productivity of the oceans were also made, and they are interesting; they were conducted by the radiocarbon method -- a study of radioactive carbon fixed by plankton. The results of geomagnetic observations have not been published as yet.

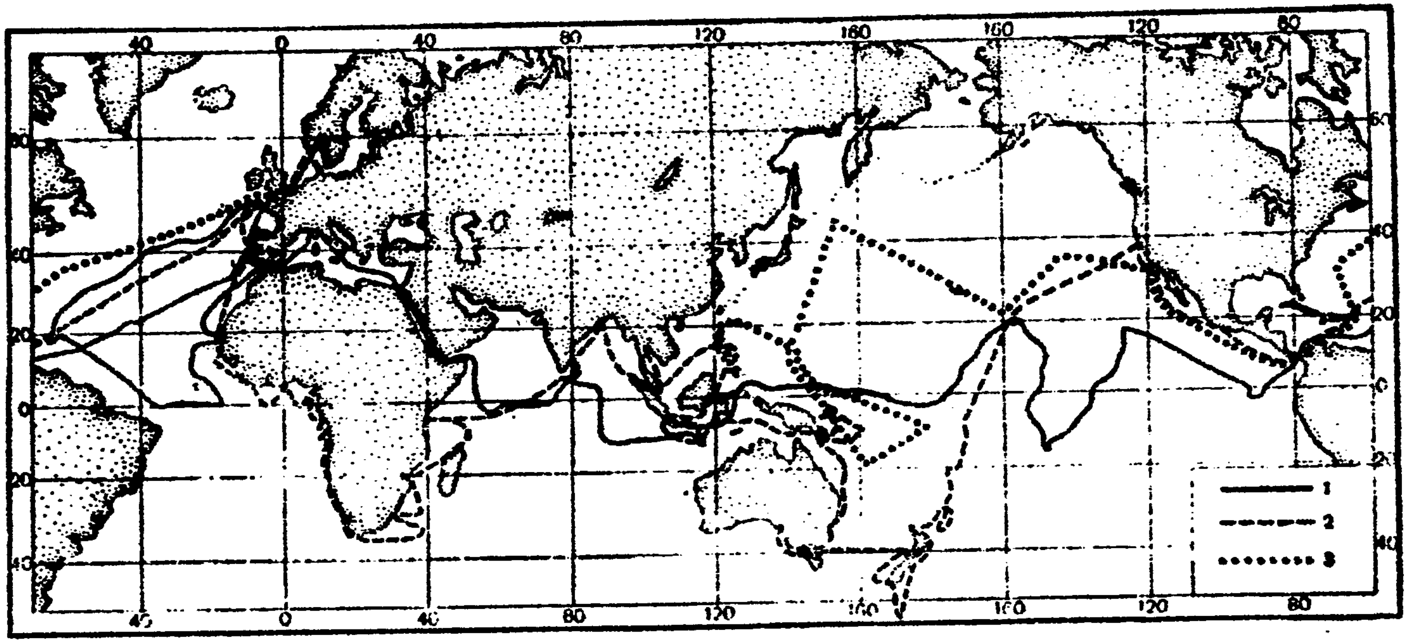

Fig. 5. Itineraries: 1 -- "Albatross," 2 -- "Galatea," and 3 -- "Challenger" (schematic and incomplete)

The round the world expedition of the "Challenger" (Fig.6) was sponsored by British scientific hydrographic institutions. This ship of 1,140 tons displacement was built in 1931 and bears the name of her famous predecessor, the "Challenger" which completed a round the world voyage between 1872 and 1876. The new "Challenger" was equipped with modern automatic echo-sounding devices, bathythermographs, the latest apparatus for seismic measurements at sea, and with standard equipment for magnetometric and biological research. There were 95 people in the crew of the "Challenger," but only three scientific workers. Seismic investigations were conducted by Haskell of the Anglo-Iranian Oil Company and Swallow of Cambridge University. Magnetometric and biological observations were conducted by the ship's physician, D. Haines. Standard bathythermographic investigations, recording of temperature and water salinity were conducted by the captain and officers of the "Challenger." H. Ritchie was in command of the "Challenger." The expedition had three main purposes.

1. Continuous echo sounding the route to determine depth, and with particular attention paid to little-known banks which are important to navigation. Hydrographic investigations were the main object of the expedition.

2. Hydrological investigations and taking of water samples with bathymeters from depths up to 4,000 m, to supplement data collected by previous expeditions. The surface water temperature

was taken hourly, and bathythermographs were lowered three times every 24 hours.

3. Investigations in the field of geology and seismism, and simultaneous biological and magnetometric observations.

Fig. 6. The ship of the British round the world expedition "Challenger " 1950 - 1952.

The expedition left Plymouth on May 1, 1950 and ended at Portsmouth on September 29, 1952, i.e., it continued for 29 months. The itinerary took the expedition across the Atlantic Ocean to Bermuda, through the Panama Canal to the Pacific, along the coast of North America to Vancouver, then across the Pacific to Hawaii, the Aleutians in the direction of Japan, and then: New Guinea -- New Zealand -- Fiji Islands -- the Marianas

canyon -- Japan -- Hong Kong -- Java -- Colombo -- Seychelles Islands -- Red Sea -- Mediterranean -- Gibraltar -- England.

The scientific results of the expedition have not been fully published as yet; there are only sporadic articles in different areas of research, especially seismism. The hydrographic material of the expedition which is apparently very voluminous and valuable, as we can judge from the section of a detailed measurement plotted on the chart of the expedition's route, has not been published.

A total of 17 complete hydrological stops were made during the expedition when water samples were taken with bathymeters; along with echo sounding, some interesting observations were made concerning the vertical migration of phytoplankton noted on echographs. The echo horizon in the upper layers of water near the coast of California was at a depth of 40 to 60 m at night and at about 300 m in the daytime. The rate of the vertical shift of the echo horizon was about 4 m/min during the morning and evening hours when the echo layer was descending, and 2 to 3 m/min when it was rising. This rate was observed for 5 consecutive days. A plankton net, lowering into the echo horizon by indications of the echo sounder, as a rule brought up a lot of calanus, medusae, euphausidae, pteropoda, sagitta, etc. No fish was caught in these places, however, there were recordings on the tape of the echo sounder similar to those observed when fish

amass. This echo layer was so dense that pulses reflected from the true floor did not reach the receiver of the echo sounder and the false echo could easily be confused with the true. It is probable that the discovery of a number of banks in the Pacific Ocean is associated with this kind of interference; they were recorded on tapes of automatic echo sounder, but were not found during subsequent investigations.

The preliminary data of the "Challenger" expedition on echo sounding which are available to us indicate that there are many underwater mountains in the Pacific Ocean, rising to between 2,000 and 3,000 m above the surrounding floor. In a number of cases the tops of these mountains miss the ocean surface by 30 to 50 m, and represent an industrial and navigational interest. It was noted, in particular, that migrating seals concentrate close to the tops of underwater mountains, apparently using the underwater mountains for feeding during their trip.

One of the most interesting results of the "Challenger" voyage was the discovery of the greatest depth of the world oceans -- 10,863 m in the Marianas canyon. This figure was made more specific by the "Vityaz'" expedition in 1957, and at the present time 11,034 m should be considered the greatest depth of the oceans.

Most fully illustrated in print are the expeditions achievements in the field of determining the thickness of porous

sediments on the ocean floor. New seismic apparatus was used for this purpose. Explosion impulses were received by means of radio buoys which were placed along the profile at a distance of 1 to 6 miles from each other. The hydrophones of the radio buoys were lowered to between 20 and 30 m. The work was conducted by the broken wave method, and the weight of BB charges fluctuated between 40 and 100 kg. The data obtained concerning the thickness of bottom deposits and the propagation of sound within them make it possible to conclude that regions occupied by the oceans at the present time differ by their geological structure sharply from the continents, and oceans apparantly came into existence in remote antiquity. This is confirmed by the seismic cross section of the sediments on the ocean floor. Under the layer of porous deposits, the ocean bottom contains rocks in which sound propagates at a speed of 6,300 m/sec, which corresponds to the basalt indicator.

The speed of sound is lower in the underlying horizon of the continents, it is between 5,000 and 6,000 m/sec. Particularly sharp differences are encountered in the location of the Mohorovicic divide, which is much closer to the surface in the oceans than under continents. Seismic investigation of the Pacific ocean atolls confirmed the correctness of Darwin's hypothesis on the development of atolls on ancient volsanic cones which are in a state of slow sinking. It was determined by seismic investiga-

tions that the thickness of porous sediments in the Pacific and Indian Ocean is smaller than that in the Atlantic Ocean by a factor of two to three. This is probably associated with the rate of sedimentation and conditions of sediment formation in these oceans, and not with a difference in their age. It is also possible that the thickness of sediments in the Indian and Pacific Ocean is associated with the presence of seams of basalt lava.

It should be considdred that the stops made by "Challenger" in the Atlantic were generally made closer to land than in the Pacific, and bottom deposits were represented by the relatively faster forming globigerina silts. Finally, the stations in the North Atlantic are located in the zone of ice thawing during the period of the last glaciation.

It would be interesting to make the following calculation: the rate of the present sedimentation of globigerina silts equals approximately 1 cm per 1,000 years. If we would accept this rate as applicable to the geological history of the oceans and constant within approximation, and if we would assume that the oceans were formed about 2 billion years ago, the thickness of porous deposits on the ocean floor should constitute about 10,0 m. This considerably exceeds the results of direct determination of thickness by seismic method, which is 500 to 1,000 m. Such a great difference can be explained by fluctuations in the rate of sedimentation in the past, and particularly by the fact that the

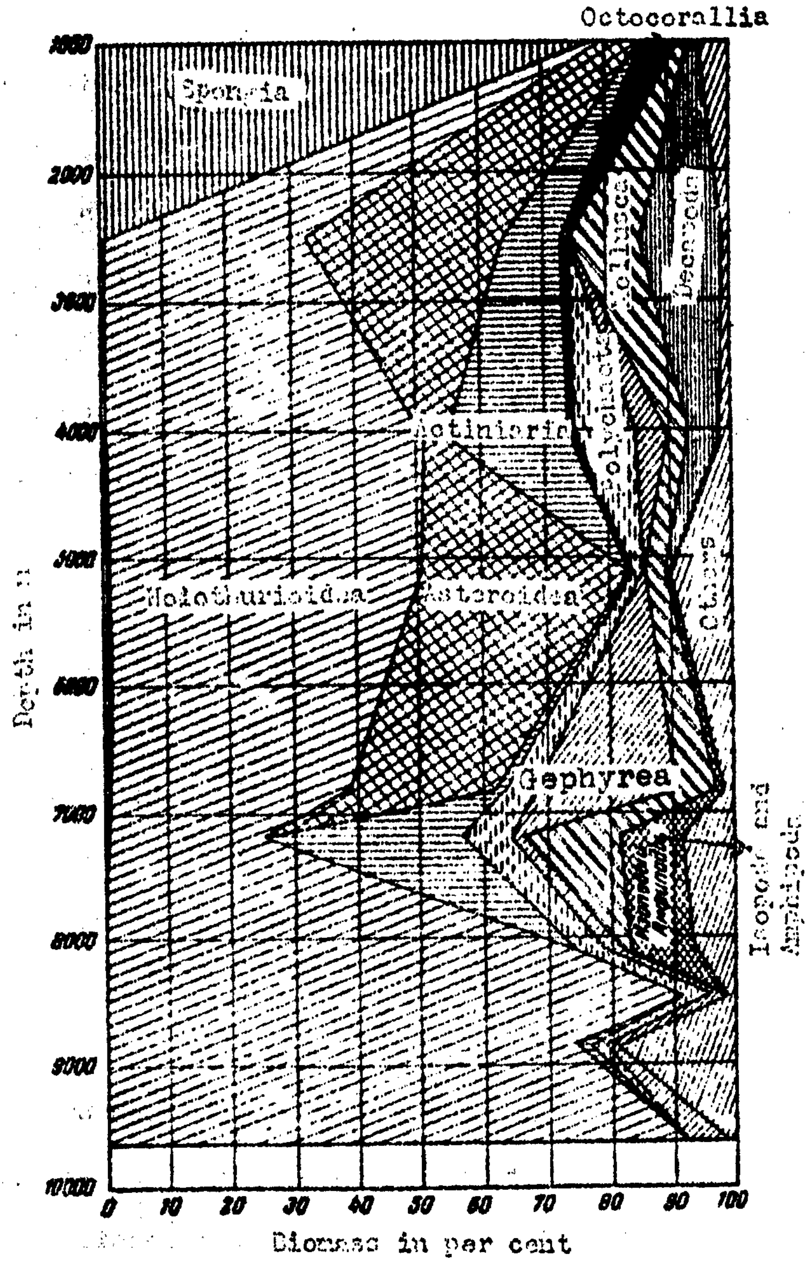

Fig. 8. Change according to depths of the percentile relationship (by weight) between various groups of bottom fauna in the Kurilo-Kamchatskaya Trench /27/.

rate of sedimentation in the oceans at the present is much higher than in the geological past. The increased present rate of sedimentation in the oceans may be associated with a higher stand of the continents and with an increasing role of organogenic sedimentation.

There is also a very interesting conclusion made by Haskell and Swallow to the effect that there is a possible gradual transition from the structure of continents to the structure of the ocean floor.

Data on biological and magnetometric observations have not been published as yet.

Thus, as far as we can judge by the published material, the "Challenger" expedition provided the most interesting material in the field of geology of the ocean floor and in the field of geomorphology.

It is evident from what has been said above that the data newly collected by four large research expeditions during the past 10 years, pertaining to the nature of the oceans, represent extraordinary interest. However, we must also consider some shortcomings in the organization of work of the three foreign expeditions, which we pointed out before. It is to be noted that due to small laboratory space and a small number of scientific personnel, the foreign expeditions were not complex oceanographic expeditions -- each one was set in a definite direction. This puts

a definite imprint on all the results obtained. The limited programs of the investigations did not make it possible to get a sufficiently complete picture of the interrelation and interdependence of natural phenomena, and did not provide a sufficiently full understanding of the nature of the oceans.

The "Galatea" expedition had the most numerous personnel, 20 persons, while the "Challenger" had only 3 scientific workers. It is hardly possible to solve the quite considerable problems facing an expedition ship with such forces.

It is also necessary to note the relatively short duration of the undertakings which limited the possibilities of research. Work was interrupted at a moment when it would seem that two years of research should have been yielding further fruitful prospects. The very nature of all three itineraries contributed to greater intervals between stops and to a certain fragmentarity of the results.

It is necessary to note in conclusion that the above mentioned stage of oceanographic investigations is associated with a considerable development of international relations.

Several international associations have come into existence in the past several years, dedicated to the development of oceanographic, and particularly deepwater exploration. The so-called IACOMS (International Advisory Committee on Marine Science) has been part of UNESCO for two years, and the International Council

of Science Unions ("ICSU") has established a Special Committee of Ocean Research ("SCOR"). Attached to this Council there is also an International Committee on Deepsea Research and its journal "Deepsea Research," which is international in scope. Lively activities are observed again in the International Council for Sea Study (ICSS") which was founded 55 years ago.

It is particularly important for the sake of international cooperation in the field of the study of oceans and in the exploitation of their raw material resources that the open spaces of the oceans and numerous seas do not belong to any state individually.

INVESTIGATIONS OF THE FLOOR RELIEF OF SEAS AND OCEANS

by G. B. Udintsev

Successful studies of the submarine relief largely depend on the quality of the technique and on the method employed. The object of the investigation, hidden from the observer's eyes, can be studied with the necessary attention to details only on condition of using sufficiently perfected technical means and methods. World War II gave rise to intensive development of hydroacoustic engineering and navigational aids. It was possible to use all these means within the past few years in hydrographic and oceanographic investigations for peaceful purposes, first of all in the study of the submarine relief. Further engineering developments in the postwar period even more accelerated improvement of tools and methods of depth sounding and of plotting a ship's position on the open sea. The general level of the scope of oceanographic work showed in the organization of large expeditions and in the completion of large systematic and complex studies which contributed to a rapid amassing of new information on the floor relief of seas and oceans. The collected facts permitted, in turn, to draw important inferences; new hypotheses appeared, and considerable success was achieved in stating and developing some important

problems of marine geomorphology. All this makes it possible to regard the postwar period in the development of oceanography as a stage which is qualitatively different from the preceding period.

A concentration of the efforts of all nations on the investigation of the oceans of the world during the period of the International Geophysical Year justified the expectation of a new upsurge of oceanographic investigations in the near future, and this promises to advance our concepts of the submarine relief even farther ahead.

Technique and Method of Investigation of the Submarine Relief

Depth sounding is the basic method of studying the relief at the present time. It was characteristic of the preceding period of investigation that there was an almost complete abandonment of the heretofore widely used method of line sounding of depths during the prewar years, and its limitation to the mere role of a check method. The sonic method is now the principal method used in echo sounding, and its use in the practice of oceanographic and hydrographic work began in the late 1920s and early 1930s. Due to the improvement of their design, echo sounding devices have become so effective in solving the problems of investigation that in the postwar period no expedition of any significance would do without them. The basic property of modern echo sounders lies in the fact that they afford an opportunity of continuous automatic recording of the depths, and this

makes them widely applicable in research practice; measurements are made very frequently and with great accuracy; their power is sufficient to measure the very greatest ocean depths, and they are compact and reliable in operation and simple to serve.

The most complete assortment of different types of echo sounders had lately been produced by the firms "Kelvin & Hughes" (Great Britain), "Bendix" and "Electronic Corporation" (USA), "Atlas-Werke" and "Elak" (West Germany), and by the Soviet shipbuilding industry /85, 89, 148, 411/. The postwar production of automatic recording echo sounders which ensure reliable measurement of the very greatest ocean depths in deepsea trenches is an important achievement of sound measurement engineering; echo sounders of this type had been unique for a long time. Now they are produced by the British firm "Kelvin and Hughes" /279/, by the American firm "Edo" /185/ and by the Japanese firm "Nichon-Denzi." Most interesting for research purposes are the precision echo sounders which make it possible to detect even the smallest relief shapes, and echo sounders equipped with electron-ray tubes used for the study of the nature of the floor soil and for detecting fish. Such echo sounders are produced, in particular, by "Kelvin and Hughes," "Bendix," "Atlas-Werke," "Elak," "Nichon-Denzi" and some other companies.

Descriptions of the new types of echo sounders produced in the postwar period are contained, on the one hand, in numerous

company publications of the "Service Instructions" type, and, on the other hand, in a number of review articles on the subject and in manuals on electro-navigation equipment /94, 113, 122, 131, 168, 183, 185, 221, 222, 268. 420, 426, 436/. Technical descriptions of echo sounders and their basic characteristics can also be found in a number of works on the use of echo sounders for research purposes /1, 2, 89, 92/. Problems of further improvement of echo sounders for research purposes have been examined in a number of articles /251, 283, 310/. Problems of developing the technique of sound measurement of depths and the latest discoveries in this field are also expounded in some popular science articles /102, 179, 230, 435/.

The wide introduction of echo sounders into the practice of geomorphological research required a development of problems of methodical sound measurement of ocean depths. These problems were first explained in a plan of method of hydropgraphic operations /10, 64, 222, 314, 333, 432/. This can be explained by the fact that echo sounders were fairly widely used in practical hydrographic research, much earlier than in practical oceanographic research; in the latter echo sounders were used for a long time only by large individual expeditions. With increasing oceanographic research, a need arose for the development of special methods of echo sounding measurements. The point is that in spite of the single object of study and a considerable community of

purpose, there is still the well-known divergence of tasks facing research of the floor relief in the sector of hydrographic and in the sector of oceanographic work. In the former case the floor relief interests researchers from the viewpoint of its relatively narrow navigational characteristics, while in the latter case it is from the viewpoint of more wide and complete characteristics, as the background of all natural phenomena occurring in the ocean, as a mirror of the geological structure and history of the development of regions of the earth's crust, which are hidden by the waters of the seas and oceans. In this connection, problems of method of studying the underwater relief by means of echo sounders had already been worked out in the light of the purposes of oceanographic research /88, 95, 249, 283, 285/.

The main theses of the methods of researching the underwater relief, developed in recent years, point to the need of a rational selection of a type of echo sounder, and of a method of its operation commensurate to the depths and nature of the floor surface. This method of operation ensures accumulation of the most detailed and accurate data which would subsequently make it possible to produce a definitely complete picture, under presently existing technical possibilities, of the floor surface of the seas and oceans. Methods are also proposed to process the collected material in such a manner as to present it in a sufficiently

clear way, so that it would be most suitable for oceanographic and geological interpretation /329, 422/.

Some problems of methods of operating echo sounders are equally interesting to hydrography as well as oceanography: these are the problems of correcting depth findings by correction for the speed of sound in water and for the effect the bottom slope may have, the problem of the accuracy of depth measurements, and the problems of deciphering echograms. In view of its complexity, special interpretation was made of the method of calculating the speed of sound in water according to hydrological observation data at stations /88, 136/, and of the methods of calculating corrections for the speed of sound between stations /64, 97, 108 a, 285/. A wide discussion was caused by problems connected with the effect of floor slopes on the operation of echo sounders which, as is known, produces errors in depth measurement and distortions of the floor profile on echograms; also problems of the principle of deciphering echograms /89, 95, 105, 210, 218, 219, 223, 249, 377 to 381, 432/. Much attention was paid to problems of special geological deciphering of echograms for the purpose of estimating the nature of the soil and stratification of bottom sediments /18, 87, 109, 110, 139, 267, 333, 358, 396, 410/. The problems of accurate measurements od depths by echo sounding are referred to, in greater or lesser degree, in all the works

cited above, some articles, however, were dedicated to these problems exclusively /107, 136, 379, 432/.

There is much interest in the possible use of echo sounders not only in the study of the underwater relief, but also for wider purposes, for example, in hydrobiological research. Studies are made of the possible determination of the position of fishing nets and other fishing equipment in the water by means of echo sounders /24/, and research is made of the behavior of marine animals /272, 382, 444/. Within the past several years scientists have paid particular attention to the possibility of locating fish by echo sounding, and to the study of the causes of the existence of a sound-propagating layer in the water which was also discovered by means of echo sounding. A large number of works have been published in recent years whose authors not only express general ideas on the possibility of locating fish with echo sounders, but give reports of experiments in such seekings and provide practical recommendations of using the new method /1, 2, 24, 85, 89, 220, 265, 375, 376/.

The problem of the sound propagating layer produced a voluminous literature; a majority of the authors perceive its cause in masses of plankton, pelagic fishes, and, in some cases, in a jump of the density of water /20, 147, 161, 171, 250, 253, 254, 255, 271, 272, 313, 319, 368, 371, 395, 417, 425, 427/.

The problem of fixing the position of a ship which is mea-

suring depth is of the utmost importance in the method of investigating the underwater relief. For a long time all means of fixing a ship's position were limited to the usual navigational methods and their accuracy was relatively low, especially on the high seas, far from visible shores. The lack of any real possibility of detailed area investigations of the underwater relief was a very annoying result. This is explained by the fact that a closer spacing of the measuring positions with an insufficiently accurate determination of their location produced contradictory data on depths and precluded the plotting of detailed charts. During the postwar period, in connection with the development of new radio engineering methods of fixing a ship's position, considerable changes affecting this problem have taken place.

The accuracy of determining a ship's position even at a great distance from land has become much higher, and finally there exists an opportunity for broad detailed studies of the underwater relief. The latest methods of fixing the position of a ship are described in a number of special articles and in general manuals on hydrographic operations /64, 120, 148, 149, 339, 411/. Articles have also appeared describing the methods and results of detailed studies of the floor relief of the seas and oceans obtained by means of the latest radio technique methods of fixing the position of a ship /123, 228, 231, 274/.

Along with echo sounding, which plays the principal part in studying the underwater relief, two new engineering methods are recently finding ever wider application in the practice of oceanographic operations: underwater photography and underwater television. Underwater cameras for photography of the ocean floor are automatic devices lowered on cables and capable of taking series of pictures. The design of underwater cameras was rapidly improved, and fine results are obtained with them now even at great ocean depths /30, 31, 57, 158, 184, 198, 343, 366, 374, 431/. Photography of the ocean floor makes it possible to obtain valuable information about the smallest shapes of the relief which are important in understanding the nature of some relief-forming processes, as, for example, the effect of bottom currents and of living organisms, as well as in explaining the properties of present-day sedimentation, underwater landslides, and relic forms of the subaeral relief encountered on the floor /190, 320, 347, 385/. In this connection, there has lately been a noticeable trend to conduct studies of the underwater relief by means of echo sounding and by means of a close network of simultaneous underwater photography, which help to get a correct interpretation of echograms /31, 193, 227, 307/.

It must be noted that underwater photography is also successfully used in taking pictures of objects in the water discovered by echo sounding, but difficult to recognize /271, 372/.

Underwater television opens great prospects to research of small relief shapes of the floor; its engineering has successfully developed in recent years, but it is thus far mainly used in solving biological problems /19 a, 84, 125, 126/.

The Organization of Research of the Underwater Relief

In the postwar period research of the floor relief of the seas and oceans was conducted on a very wide scale by many countries which have their own navies and which are interested in the development of navigation and marine industry. This research was mainly carried out within the framework of two principal organizational forms: in the form of incidental research by individual large and complex oceanographic expeditions conducting operations in large areas of the seas and oceans, and in the form of organizing special expeditions conducting lengthy and planned studies of the underwater relief within the limits of certain seas and within limited sectors of oceans. The first includes certain round the world expeditions investigating large areas of the oceans, and the second includes numerous expeditions on a relatively smaller scale repeatedly conducted by different oceanographic institutes and laboratories for the purpose of solving individual scientific problems, as well as

most hydrographic expeditions. Even an incomplete list of the various kinds of expeditions in recent years in quite large /130/.

There are essential differences in the nature of the material obtained by the different types of expeditions. The big complex expeditions are noted for the essentially detecting nature of the study of the underwater relief. The need of investigating huge areas of the ocean within a relatively short period, predetermined, in turn, a comparatively simple itinerary and a wider spacing of positions at which incidental measurements were taken. Materials thus collected, could naturally not provide a complete picture of the floor relief of the oceans of the world as a whole, nor of any considerable part thereof, and only in cases of completing particularly detailed studies in a few especially interesting regions (for one reason or another), did they satisfy the requirements of the geomorphologists as far as details were concerned. Due to the fact, however, that all the large oceanographic expeditions in recent years were equipped with the latest devices, considerable numbers of experts took part in them, and they were conducted by advanced methods, the materials collected by these expeditions were extraordinarily interesting, in spite of the obvious superficiality of the investigations. As a rule, these materials prove to be exceptionally important in the detection of the most conspicuous

and common features of the floor relief of the world's oceans, in posing a number of problems of marine geomorphology, and in clarifying the ways by which they can be solved in further and more detailed investigations. On the other hand, the specializing expeditions concentrated their efforts on a planned and prolongued study of objects limited in scope. The expeditions collected materials which provided a most complete and detailed idea of the floor relief and which made it possible to draw a number of conclusions concerning its origin, the history of its development, connections with other natural phenomena of the sea, concrete geological and oceanological circumstances, as well as an important basis for the solution of a number of problems of marine geomorphology.

The sweep of oceanographic research during the postwar period was primarily reflected in the scope and the large oceanographic expeditions, both round the world as well as those limited to the study of individual oceans. The round the world Swedish expedition on the "Albatross" lasted through 1947/1948, and during its course considerable material was gathered concerning the floor relief in the equatorial waters of the oceans /284, 285, 351, 352, 353/. The most important results of the investigation of the underwater relief completed by this expedition were: new correct concepts of the complexity of the ocean floor relief, and of the diversity of small shapes on the su-

face of the ocean floor. During 1951 to 1952 two large round the world expeditions were conducted almost at the same time: the Danish oceanographic expedition on the "Galatea" and the British hydrographic expedition on the "Challenger." The main purpose of the "Galatea" expedition was a complex oceanographic study of deep-sea oceanic trenches*. The greatest success of the expedition was the detailed study of the relief of a number of deep-sea trenches: the Philippine, the Marianas, the Bougainville, the Kermadek, and Tonga /144, 280, 443/. The hydrographic expedition on the "Challenger" made only reconnaisance study of the relief incidentally along the itinerary, which approximated the itinerary of the first "Challenger" expedition of 1872 to 1874. At the same time, however, it completed a detailed study of underwater mountains discovered along this itinerary. Among the achievements of this expedition, prominent place should be given to the measurement of the new maximum ocean depth, discovered as a result of detailed studies of the

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* At the present time two terms are simultaneously used in literature on ocealogy and marine geology which are synonyms: deep-sea ocean canyon and deep-sea ocean trench. The second term is closer to that accepted in international usage and recommended for use by the International Committee on Nomenclature for the shapes of the underwater relief: "trench." In this connection, this article uses precisely the second term -- deep-sea ocean trench, although in a number of works in Russian one can encounter the term deep-sea ocean canyon which means the same.

floor relief of the Marianas deep-sea trench /111, 153, 226/. The results of the study of underwater mountains discovered by the expedition are also of major interest /224, 225, 357/.

The Scripps Oceanographic Institute (USA) conducted a number of large expeditions in the Pacific Ocean. Thus, this Institute's "Midpacific" expedition of 1950 was made for the purpose of studying the central part of the Pacific Ocean. The results of the work of this expedition provided new material for a correct concept of the nature of the floor relief of the Pacific Ocean, of the distribution of underwater mountains, and of their association, in particular, with the massive rise bisecting the western part of the ocean in a latitudinal direction. The expedition discovered a series of heretofore unknown underwater benches in the eastern part of the ocean, which are positively of tectonic origin, and which represent one of the most interesting peculiarities of the structure of the earth's surface /175 a/. The "Capricorn" expedition was conducted in the southern tropical part of the Pacific Ocean in 1952 to 1953. Data concerning the floor relief of the ocean were gathered by the expedition along the entire itinerary; in addition, detailed studies were made of the floor of the Tonga deep-sea ocean trench /150, 361/. The measurement of the maximum depth in the Tonga trench is one of the achievements of the expedition /212/.

The "Transpacific" expedition, conducted in 1953, encom-

passed the peripheral sectors of the Pacific Ocean. This expedition investigated the floor relief along the entire itinerary and this provided a comparison of morphological peculiarities of different regions of the Pacific Ocean. The expedition also conducted fairly detailed investigations in the Japanese and Idzu-Bonin deep-sea trenches, and investigated part of the northern extension of the Hawaiian underwater ridge /211/.

Reconnaissance work on a large scale was completed in the Pacific Ocean in recent years by the complex Soviet oceanographic expedition of the Institute of Oceanology Acad Sci USSR on the "Vityaz'." Between 1953 and 1955 this expedition operated in the northwestern part of the ocean. Studies of the underwater relief were conducted along the entire itinerary of the "Vityaz'" and made it possible to detect a number of important peculiarities in the morphology of this part of the Pacific which were heretofore unknown /29/. Differences were discovered in the nature of small relief shapes which are peculiar to many regions of the ocean, and numberous underwater mountains were discovered and investigated. A study was made of the particular correlationships of deep-sea trenches in the northwestern part of the Pacific Ocean. The Kurilles-Kamchatka trench has been studied in greatest detail, with measurement of a new maximum depth, and the northern extension of the Hawaiian underwater ridge which was heretofore essentially unknown /7, 98, 100, 101, 104/.

Work conducted by the Soviet high-latitude expeditions in the North Arctic Ocean in the st dy of the underwater relief was of the reconnaissance type. These expeditions were crowned with extraordinary success -- the discovery of one of the most important features of the ocean floor relief -- the Lomonosov underwater ridge, unknown to this time /74/. Reconnaissance work in the study of the floor relief in the North Arctic Ocean was also conducted by American high-latitude expeditions, but the scope of the American investigations and the results are far behind the Soviet /57, 162, 162 a/.

Work was continued during the postwar period by the British oceanographic expedition on the "Discovery," which had been working in the Antarctic waters for a number of years before World War II /165/. The work of the "Discovery" expedition was directed toward the study of the most conspicuous features of the floor relief of the Antarctic Ocean. Work in the study of the floor relief conducted by the American Antarctic Expedition /172 b/ was of a similar nature. Soviet work, developed in the very latest time in the Antarctic Ocean constitute, on the one hand, reconnaissance investigation of the underwater relief in the immense regions of the subantarctic waters, and, on the other hand, a detailed study of the relief of the continental slope and of the submerged border of the Antarctic continent /41, 59/.

The large oceanographic expedition which are, as we have noted, of a reconnaissance nature, represent only a part of the organized plan according to which studies of the floor relief of the seas and oceans have been conducted during the postwar period. On a somewhat smaller scale, but more systematically and according to plan, studies were conducted by specialized expeditions of a number of research institutes, laboratories, and hydrographic services. We will mention only the largest of these, omitting a large number of the small expeditions which actually operated in all parts of the sea, but did not have any marked effect on the development of modern concepts of the floor relief of the seas and oceans.

Systematic investigations of the underwater relief on a large scale were conducted in recent years in the USA. Most interesting are the activities of five research institutions conducted along this line: the Lamont Geological Observatory, the Woods Hole Oceanographic Institution, the Scripps Institution of Oceanography, the Marine Electronic Laboratory of the U.S. Navy, and the U. S. Coast and Geodetic Survey. Work of the Lamont Geological Observatory is concentrated on a study of the northern half of the Atlantic Ocean, and mainly of its western part, adjacent to North America. Research was directed toward a clarification of the existing differences in the character of the small shape relief among the individual morphological

regions of the ocean, toward a study of the morphology of underwater mountains as reflectors of ultra-distant scattering of sound within the range of a channel, and toward the determination of the relief-forming role of suspended currents /200/. Works of the Woods Hole Oceanographic Institution encompass detailed investigation of the underwater relief approximately in the same regions as the work of the Lamont Observatory, and explain approximately the same range of problems. In this connection it is worthwhile to mention the investigations of the relief of the Mid-Atlantic underwater ridge, of a number of underwater mountains, canyons and deepsea plains of the North Atlantic /121, 421, 422/.

The Scripps Institution of Oceanography investigated the floor relief of the Pacific Ocean together with Marine Electronic Laboratory of the U.S. Navy. This Institution conducted the "Mid-Pacific," "Capricorn" and "Trans-Pacific" expeditions mentioned above. In addition the Scripps Institution and the Marine Electronic Laboratory conducted major work of studying the floor relief of the eastern part of the Pacific Ocean. Worth of attention are their planned investigations of the underwater canyons of the continental slope of North America, of the underwater relief of the Hawaiian island chain, of the underwater mountains of the Gulf of Alaska, as well as of the tectonic benches extending along the ocean floor for thousands

of kilometers /175 a, 176, 325, 326, 388/.

The work of the U. S. Coast and Geodetic Survey in the study of the underwater relief is somewhat peculiar by its nature. The purpose of these investigations was to study the floor relief in order to obtain its navigational characteristics. For this reason the work consisted of extremely detailed investigations and was concentrated in certain limited, but navigationally important regions /411/. A characteristic feature of this work was the extraordinarily accurate determination of the position of ships and a dense coverage of the waterways with measuring positions, thanks to which the materials of the Coast and Geodetic Survey began to be highly objective in transmitting a picture of the underwater relief. During the postwar years the investigations of the Coast and Geodetic Survey encompassed the Gulf of Mexico and the Aleutian Island chain. Charts composed from the materials of these investigations give an extremely detailed idea of the underwater relief. Similar work on a somewhat smaller scale was conducted by the U. S. Hydrographic Office; the object of the investigations were the areas of the continental shelf along the Atlantic coast of the USA.

The Great Britain investigations of the underwater relief during the postwar years were conducted, on the one hand, by the 'Discovery' Committee subsequently transformed into the

National Oceanographic Institute, and on the other hand, by the Hydrographic Office of the Admiralty. The latter, in particular, organized the "Challenger" expedition. British expeditions conducted systematic studies of the floor relief in the eastern part of the North Atlantic; especially broad operations were conducted near the Faroe-Shetland shelf, near the Iceland-Greenland shelf, in the Bay of Biscay, and near the entrance to the English Channel /263, 282/.

Other foreign countries were much less active in a systematic study of the underwater relief during the postwar years. West Germany conducted expeditions on a relatively small scale, making systematic studies of the North Sea floor. They were organized by the German Hydrographic Institute /138, 394/. In the work of this Institute much attention is paid to problems of method and to investigation of small relief shapes which are interesting both from the practical viewpoint of securing sea fishing, as well as for theoretical research in connection with the problem of the Quaternary history of the continental shelf of Northern Europe. In France marine geomorphological work is undertaken by the Laboratory of Marine Geology in cooperation with the Hydrographic Office. This work is mainly done on the continental shelf and partly on the continental slope close to the French coast in the Atlantic and in the Mediterranean, as well as close to the shore of French North Africa /127, 128,

/140, 141/.

Investigation of the floor relief of the Red Sea was begun by a French oceanographic expedition on the "Calypso" /180/.

After a long interruption, investigation of the floor relief of the Mediterranean has been resumed by Italian hydrographers and Yugoslavian oceanologists /235, 383/. Numerous Japanese research institutions are conducting planned studies of the underwater relief near the Japanese coast for the purpose of examining the industrial base of the fishing industry. Activities have been resumed by the Hydrographic Office of the Japanese Navy which has concentrated its attention on a study of the floor relief near the shores of Japan /261, 262, 341, 343, 412/. Within a relatively short time the Japanese oceanologists and hydrographers have collected interesting material on the relief of the continental sehlf and of the continental slope of Japan, and on the underwater relief of the Idzu-Bonin island chain.

In the Soviet Union systematic planned studies of the underwater relief were carried out by a number of scientific-research institutions and by the Hydrographic Administration. We will note the most important trends of these works. In the seas of the Far East investigations of the floor relief have been conducted by the Institute of Oceanology Acad Sci USSR since 1949. As a result of this work a detailed study has been made

of the floor relief of the western part of the Bering Sea, of the Sea of Okhotsk, of the region of the Kurile island chain, of the Sea of Japan, and of the Kurile-Kamchatka ocean trench /8, 29/. Much attention is paid to the study of small relief shapes in order to learn present-day relief-forming processes, paleogeographic reconstruction in connection with the study of geological structure and the history of the development of the Far Eastern seas. A separate chapter is represented by works on the study of the floor relief of some regions which are important to industry and navigation. The Institute of Oceanology has also begun a planned study of the floor relief of the Black and Caspian Sea using the latest methods /91/.

The scientific-research institutes of the Soviet fishing industry have, for a number of years, been conducting planned studies of the floor relief of the Azov, Baltic, Barents, Norway and Greenland seas. Especially noteworthy are the investigations of the floor relief of the Barents Sea by the activity and scope of the work; they are conducted by the Polar Institute of the Sea Fishing Industry and Oceanography. At the present time the Institute is developing wide operations in the study of the underwater relief of the sea of Norway and Greenland /21/. The Pacific Ocean Institute of the Sea Fishing Industry and Oceanography, together with the Institute of Zoology Acad Sci USSR, has conducted studies of the floor relief of some regions of the

seas in the Far East /112/. The floor relief of the northern seas of the Soviet Union in being investigated by systematic studies conducted by the Arctic Scientific-Research Institute of the Main Northern Sea Route /86/. Quite recently, the Institute of Oceanology Acad Sci USSR has started a study of the floor relief of the Antarctic Ocean.

It is clear that the years following the Second World War are noteworthy for the ever growing scope of investigations of the floor relief of the seas and oceans. The number of large complex expeditions is growing, and the network of systematic photographs is getting denser. The scope of the work considerably exceeds all what had been done in this field in the course of the first decades of this century /129, 130, 339/. Use of new investigation techniques has opened new opportunities of the study of small shapes of the floor relief of the ocean which had disappeared from the field of vision of the geomorpholigists, the study of the deepest ocean trenches, and of the complicated relief of the continental slope. The organization of such large international expeditions as those realized by the program of the International Geophysical Year /66/ serves as a prerequisite for changing the nebulous and dim concepts which have prevailed until recently which will be replaced by a clear and detailed picture of the floor relief of the world's ocean in the near future.

Basic Results of Regional Investigations

The Atlantic Ocean, by reason of its geographic position, is today one of the most important objects of oceanographic investigations. In recent years the attention of researchers was principally concentrated on a study of the North Atlantic, which is quite natural, if we consider the location of the main sea lanes and regions of maritime industries. The North Atlantic has long attracted the attention of researchers, thanks to which the floor relief of this half of the ocean had been studied in general outline quite well even before the war. The application of new techniques and methods, however, made way for considerable new achievements also in this case.

The basic peculiarities of the floor relief of the North Atlantic are described in detail in the works of Tolstoy and Ewing /422/, Emery /188/, Tolstoy /421/, Heezen, Ewing and Ericson /244/, Ewing and Heezen /200/ and Hill /263/. The most complete bathymetric charts drawn from material of the latest investigations are given in the works of Tolstoy /421/ and Hill /263/.

The most important feature of the underwater relief of the North Atlantic is the existence of a huge structure of the Mid-Atlantic ridge, extending from the shores of Iceland southward across the entire North Atlantic and then across the

southern part of the ocean to within the region of Tristan da Cunha Island. This is a massive mountain structure; its width, including the foothills, ranges from 300 to 500 miles (to 500 km), and in the highest part equals about 50 miles (90 km). The altitude of the underwater ridge reaches 3500 to 4000 m above the floor of the surrounding basins. There are three distinct morphological zones of the ridge:

1. The highest central zone; it is characterized by numerous parallel ridges oriented along the main direction and rising to depths less than 1,500 m with their rocks and precipitous peaks. Located approximately along the axis of this zone is a longitudinal trench which, by its morphological peculiarities, can be compared with the East African grooved valleys. Specimens of rocks occurring in their place of origin were taken from the peaks and slopes of the central zone of the Mid-Atlantic ridge: fragments of olivine basalt, pieces of lava, and volcanic ashes /151, 373/. The origin of the relief of this ridge zone is associated with intense tectonic dislocations and volcanic activity.

2. The so-called terraced or intermediate zone; it extends along both slopes of the Mid-Atlantic ridge at depths from 2,900 to 4,500 m. This zone is characterized by an extensive rolling relief and broad flat plains located at different levels. The formation of these flat plains or "terraces" is asso-

ciated with a filling of the depressions of the primary tectonic relief with masses of sedimentation material, deposited from the slopes of the central zone by turbidity currents /244/.

3. The outer hilly zone; it represents the foothills of the ridge. It extends on both sides of the ridge and separates the intermediate zone from the floor of the adjacent basins.

Thanks to the existence of the Mid-Atlantic ridge and the peculiarities of the configuration of the continental slopes, several basins are clearly distinguishable in the North Atlantic: the Newfoundland, the North American, the North Canaries (North African), and the North-Eastern. The floor of these basins consists of wide plains located at depths of the order of 5,200 to 5,400 m. The surface of the plains is nearly horizontal in the central parts and slightly sloping at the edges. Thus, in the central sectors the deep-sea plains have surface inclines of no more than 1 : 1,000, while along the edges the inclines are 1 : 200. Investigations of the deep-sea plains in the basins of the North Atlantic have disclosed, on the whole, an unusual flatness of their surface, which is in sharp contrast to the complex separation of the continental slopes and the slopes of the Mid-Atlantic ridge /263, 421/. Along with this, individual underwater valleys were discovered on the surface of the deep-sea plains, both in the slightly sloping outer regions, as well as in the nearly horizontal central

regions /201/.

The origin of the deep-sea plains and of the valleys within their limits was explained, as the outcome of special investigations, by the activity of turbidity currents, a powerful factor in the transfer of fragmental material, active at all depths and filling the depressions of the underwater relief with sedimentation /245/. The underwater valleys on the ocean floor are considered to be channels in which the principal mass of the current moves, and which is capable of eroding the porous sedimentation strata. A major part in the study of the mechanism and of the relief-forming activity of the turbidity currents was played by investigations conducted in connection with the underwater earthquakes of 1929 in the region of the continental slope near the Grand Banks. This earthquake produced a large underwater slide, and subsequently a powerful turbidity current which severed submarine telegraph cables and displaced them hundreds of kilometers along the ocean floor /195, 196, 242, 246/.

Numerous underwater mountains have been discovered in the North Atlantic /200, 311/. For the most part they belong to the Mid-Atlantic ridge. Part of the underwater mountains is also associated with the vast rise of the Bermuda Islands. In addition, some isolated mountains have been discovered within the range of basins in the North Atlantic. The peaks

of many underwater mountains rise to depths less than 1,500 m. Some underwater mountains are flat-topped and indications of terraces on their slopes. In places the mountains form groups; for example, a chain of mountains extends from Cape Cod to the Bermuda Islands and then to the Mid-Atlantic ridge. A similar chain of mountains also stretches from the Azores to the region of Gibraltar. Detailed studies of some underwater mountains of the North Atlantic indicate their volcanic origin, and the time of their formation is associated with chalk /245 a, 346, 393, 448/.

The deep-sea plains in the basins of the North Atlantic extend, as has been noted, at depths of the order of 5,200 to 5,400 m. The maximum depths in this half of the ocean belong to the deep-sea trenches of Puerto Rico and Romanche. Detailed studies of the relief of the deep-sea trench of Puerto Rico have made it possible to determine that this trench is about 750 km long, with very twisted slopes and a flat smooth bottom at a depth of the order of 7,900 m. The width of this flat bottom ranges from 10 to 20 km /199, 345, 355/. A wide massive bank separates the Puerto Rico trench from the floor of the plain of the North American basin located to the north. There is a number of underwater mountains within the limits of the trench which divide the floor of the trench into two separate plains: the northern, at a depth of about 7,900 m, and the

southern, at a depth of about 7,400 m. The origin of the flat bottom of the trench is explained by an intensive accumulation of sediment, carried to great depths by turbidity currents.

The problem of the maximum depth of the Puerto Rico trench is complicated by the circumstance that there are contradictory data concerning it. Detailed investigations of the trench conducted by the Lamont Geological Observatory discovered a maximum depth of 8,381 m /159, 545/, while on the basis of some other operations in this trench, the indicated depths are 9,219 and 9,155 m /512, 405/. The reports of Northrop, Ewing and Heezen seem to us to be more probable, since they are based on detailed investigations of the relief of the Puerto Rico trench.

Investigations of the deep-sea Romanche trench carried out by the "Albatross" expedition were less detailed than the American investigations of the Puerto Rico trench. The maximum depth of the Romanche trench is 7,728 according to new data. An important result of the investigation of this trench is the finding that its bottom is just as flat as of the other deep-sea trenches. The bottom plain of the Romanche trench is located at depths of the order of 7,200 to 7,400 m /285/.

In general, the depression of the North Atlantic is bounded by the rise of the continents in the east and west. The relief of the continental shelf and of the continental slope was studied in much greater detail in recent years than the relief

of the open spaces of the Atlantic Ocean. A new feature resulting from these investigation is the correct concept of the relief of the continental slope as a complex relief of the intermediate zone. It was found that there exist, within the limits of the continental slopes of the North Atlantic, along with relatively simple twisting benches, also great sectors of an open inclined and even horizontal bottom, rises and basins /263, 422/. Underwater valleys have been found everywhere within the limits of the continental slope.

Exceptionally detailed investigations of the relief of the continental shelf and of the continental slope were conducted in the Caribbean Sea /337, 365, 445/ and in the Gulf of Mexico /123/. Very detailed bathymetric charts have been plotted on the basis of these operations for the continental slope and for the shelf of the Gulf of Mexico /229/. The problems of an association of the underwater relief with tectonics were basic in the investigations /154, 155, 274, 400, 433, 434/, but along with this, studies were also made of the Quaternary history of the region and of the processes of contemporary development of the relief /198, 213, 390/.

Detailed investigations of the underwater relief were also conducted on the continental shelf of the east coast of the USA /187/. These works are particularly interesting with respect to possible paleogeographic reconstructions of conditions

of the Quaternary period, since there was here discovered a well-preserved relic subaerial glacial and erosion relief /333/. The investigations of underwater canyons close to the coast of the USA, begun fefore the war, were further developed in recent years in connection with the problem of studying the turbidity currents /344/.

The attention of researchers in the more noetherly regions of the Atlantic was drawn to an underwater ridge extending between Great Britain and Greenland. This ridge consists of several banks which have a considerable effect on the peculiarities of the water exchange between the North Atlantic and the North Arctic Ocean: the Thomson bank, the Faroe-Shetland, the Faroe-Iceland and the Iceland-Greenland. The configuration of these banks has considerably been clarified as a result of the latest research, and this in turn, makes it possible to make the nature of the water exchange more precise /169, 414/. The identification of the upper surfaces of the banks, to which rich fishing regions are attached, has made it possible to equip the sea fishing industry with detailed bathymetric charts /21/.

Detailed investigations of the underwater relief of the continental shelf and of the continental slope were conducted close to the British coast /263/. As a result, studies were made of the underwater valleys of the continental slope, of the general configuration of the continental slope which has an extremely

complicated outline, detailed clarification has been made of the floor relief of the English Channel which is important for an understanding of the geological history of northwestern Europe /234, 282.

The study of the floor relief of the North and Baltic Sea developed in the direction of detecting small relief shapes which are of great interest to paleogeographic reconstructions /381, 318, 406, 410/. Particularly interesting were the works which made it possible to detect on the bottom of these seas traces of Quaternary glaciation in the shape of terminal moraines /234, 356, 357/. Detailed bathymetric charts drawn on the basis of the latest data are of great practical importance to the fishing industries in these seas /167/.

Studies of the continental shelf and of the continental slope off the coasts of France and Spain were conducted on a relatively smaller scale, but even here the results of recent investigations provided detailed information concerning underwater valleys diving the continental slope /127, 128/.

The latest investigations of the Mediterranean floor which was quite inadequately studied earlier, have changed the concept of some quite significant peculiarities of its underwater relief and of its depths /235, 383/. The detailed study of the continental shelf and of the continental slope in the southern part of the Mediterranean simultaneously opens

greater possibilities to a careful comparison of the underwater relief with the tectonic of the land /141, 273, 302, 369/.

The results of a study of the relief of the continental shelf and of the continental slope of the Atlantic coast of North Africa provide interesting material on the Quaternary history of the Senegal delta /423, 424/.

The floor relief of the South Atlantic was not studied in such detail in recent years as the underwater relief of the North Atlantic. Information broadening earlier concepts of the underwater relief of this half of the ocean was obtained along the itineraries of reconnaissance expeditions. Thus, for example, interesting data were obtained on the existence of the same kind of deep-sea plains on the bottom of basins in the South Atlantic, as had been discovered in the North Atlantic /200/. A study was made of the relief of the southern part of the Mid-Atlantic ridge and it was observed that the surface of the floor within its limits is highly complex in structure /285/. However, the material collected in recent years on the floor relief of the South Atlantic was apparently insufficient for drawing new bathymetric charts.

The Pacific Ocean represents the greatest water expanse of the earth, exceeding all the other oceans in area. It is understandable that notwithstanding the broad scope of the investigations of recent years, the Pacific Ocean was not studied in such

details during these years as the Atlantic Ocean, and the North Atlantic in particular. In recent years the study of the floor relief of the Pacific Ocean was mostly in the nature of reconnaissance work, and the studies assumed the character of systematic research only in comparatively limited regions. The peculiarities of the geographic location of different parts of the ocean predetermined the considerable disparity of investigations. Work on the largest scale was conducted in the northern part of the Pacific Ocean, and in addition in its outskirts, which is explained by the distribution of the main sea lanes and regions of sea fishing.

The basic features of the floor relief of the Pacific Ocean are determined by the presence of a system of large mountain rises, dividing the ocean floor into a series of large basins: the Northeastern, the Northwestern, the Central, etc. The numerous mountain ranges are attached to the zone of the continental shelves of the Pacific Ocean, and separate a number of outlying seas from it's main expanse: the Bering Sea, the Sea of Okhotsk, Japan, etc. The latest investigations have introduced corrections into the earlier concepts of the basic features of the ocean relief, since precise measurements were made of the true dimensions and configuration of mountain structures and of the basins which they separate. However, the results of recent investigations had an even greater effect on the concepts of the small and medium

relief shapes of the Pacific Ocean floor. Discoveries were made of underwater mountains, a complex division of the ocean floor surface, underwater hills and valleys and benches: all this radically changes the earlier concepts about huge plains of the ocean floor, undisturbed by any wrinkles. The results of the latest investigations uncover a true picture of the multiplicity of the underwater relief in the Pacific Ocean and provide an approach to the solution of the problems of the origin of this ocean floor and of its geological history.

A number of works have already been published recently which provide the first summaries of the investigations of the Pacific Ocean floor in the past several years /166, 172 b, 441/. However, a majority of the survey works is confined to an analysis only of individual parts of this greatest ocean: the western, southwestern, northwestern and northeastern /29, 174, 257, 259, 323, 323 a, 348, 349, 357/. Bathymetric survey charts from material of the latest investigations are cited, in particular, in the works of L. A. Zenkevich, Dietz, Hess, Hess and Maxwell, Menard and Dietz /29, 177, 257, 259, 326/.

As has already been mentioned, the most important features of the floor relief of the Pacific Ocean are determined by the existence of underwater mountain massifs which separate the ocean into several principal basins. The dimensions and configurations of some of them were investigated only in recent years

Thus, it was found that the earlier known underwater Hawaiian ridge in the central part of the ocean, actually extends far north, all the way to the region of the Komandorski Islands /7, 99, 174, 211/. Consequently, the Hawaiian underwater ridge should now be regarded as an important link in a huge mountain system formed by it together with th. Fanning ridge, the Tuamotu ridge, and the Southeast Pacific rise. This colossal mountain system extends throughout the whole Pacific Ocean approximately in the meridional direction and its size can be compared with the Mid-Atlantic and the Mid-Indian ridge.

It should also be noted that the discovery of the northern part of the Hawaiian ridge compels us to speak of a division of the northern part of the deep of the Pacific Ocean into two separate basins: the northwestern and the northeastern.

Detailed investigations of the underwater Hawaiian ridge expose a number of peculiarities in its structure which differentiate it from the Mid-Atlantic ridge. The underwater Hawaiian ridge is in its entirety a wide (up to 600 miles, i.e., 1,100 km) and massive rise, about 1,000 m high, which could be called a bank, and along whose anticline part we find the mountain chain. For the most part these mountains are located so close together that their bases abut, forming large massifs, but in some places they maintain their individuality /176, 176 a, 406/. In the northern sector of the ridge the tops of the mountains are quite flat and covered with piles of smoothened pebbles. The petro-

graphic composition of the pebbles from the tops of this sector of the mountains is similar to that of the volcanic rocks of Kamchatka and the Kurilles /301/. This can possibly be explained by the similarity of the petrographic composition of the original rocks of the ridge to the rocks of Kamchatka and the Kurilles, but it is no less probable that the pebbles of this composition were carried here by ice floats in the glacial period. A characteristic feature of the anticline rise of the Hawaiian ridge is its junction, along a considerable length, with a sloping depression which extends along the eastern slope.

The Mid-Pacific bank which was investigated in recent years possesses characteristics similar to those of the anticline rise; it extends from the region of Necker Island (Hawaiian Islands) to the region of Iwo Jima (volcano). The width of this bank also reaches 600 miles (1,100 km). Numerous underwater hills are located on this bank, but they do not form joined massifs as those of the Hawaiian ridge. Many mountains have flat tops at depths of the order of 1,300 to 1,600 m.

The wide anticline rises (banks) of the Pacific Ocean floor relief proved to be an interesting feature; they are located at the edges of the ocean bottom along the deep-sea ocean trenches /101, 104, 174/. The Zenkevich rise, extending along the Kurilles-Kamchatka trench, can serve as an example of such a bank. Vast elevations, located at the bed corners at the junctions of some banks and ridges are the characteristic relief shape of

of the Pacific Ocean /99, 392/.

In addition to the underwater mountains of the Hawaiian ridge and of the Mid-Pacific bank, a multitude of isolated mountains has been discovered in the Pacific Ocean in recent years; actually they are scattered all over the ocean floor /57, 175 a, 256, 322, 325, 338, 397/. While it is true that vary many underwater mountains tend to be located on the surface of banks, or form part of the system of mountain ridges, between the banks and mountain ridges of the Pacific Ocean, on the bottom of the basins, the number of mountains is extremely large. These mountains represent just about the most characteristic feature in the appearance of the underwater relief of the Pacific Ocean. As regards the most thoroughly investigated underwater mountains, for example, the mountains of the Gulf of Alaska /325/ or of the Mid-Pacific bank /176 a/, they have round contours in the plane, twisting slopes (angle of incline up to 10 and 20°), sharp or flat and smooth tops located at depths of the order of 1,300 to 1,700 m. Specimens of rocks occuring in their place of origin taken from the tops of underwater mountains in the northern regions of the ocean consist of fragments of volcanic lava (olivine basalt), and in the southern tropical and equatorial regions they consist not only of lava fragments, but also fragments of well-cemented fauna of coral reefs of the Cretaceous age /176 a/. It is a remarkable fact that in sediments covering the slopes of underwater mountains of the Pacific

Ocean, foraminifera of the Cretaceous period were discovered /239/.

A comparison of the underwater mountains of the Pacific Ocean with the existing coral islands -- atolls -- shows signs of considerable similarity between them /174, 178, 192, 256/. It is assumed that the underwater mountains are volcanoes which were formed in the Cretaceous period. In a number of cases the tops of the volcanoes originally rose above the surface of the water, but were subsequently cut by the action of wave abrasion and served as foundations for coral structures. The submersion of flat mountain tops to their present depth is explained either by regional tectonic cave-ins of the oceanic crust, or by local cave-ins of the earth's crust under the weight of mountains /176 a, 325/. There is evidence in favor of the latter assumption in the very peculiar circular ditches surrounding the foot of some of the mountains. The circumstance that many underwater mountains completely lack coral reefs, can be regarded as an indication that in their development they lacked a stage at which the top of the mountain rose above the water. In those cases where the mountain top is covered with old coral reef, the submersion of the mountain without compensation by reef growth should be regarded as an indication of the speed of submersion, or of an unfavorable change of ecological conditions, since the results of drillings on existing atolls also show a deep submersion of the volcanic foundation and compensation of this submersion

by the growth of the reef /178, 303, 304, 305/.

For a long time the bottom of the basins in the Pacific Ocean consisted of ideal plains. However, investigations of recent years have disclosed an extreme variation of the relief of small and medium shapes. Considerable areas of the ocean floor have a complicated hilly relief, while a flat bottom is found only in the depressed floor and occupies a relatively small area. Thus, for example, along the itinerary of the American "Mid-Pacific" Expedition, the floor was a flat plain only along 37% of the route, while 63% of the route showed a surface of the floor with complicated disjunction /176 a/. The Soviet investigations of the northwestern part of the Pacific Ocean made it possible to determine that vast rises and elevations, even if they are relatively low, as well as considerable areas of the floor between them, are not perfectly flat, but have complicated disjunctions, and are covered with hills and bisected with deep valleys. In the most depressed part between the Hawaiian ridge and the Zenkevich rise the ocean floor was found to be flat, but within the limits of the plain a narrow area was discovered having an extremely complicated relief, representing a combination of mountains and trenches /349/. In our opinion the zone of such a complicated relief is the result of intense tectonic dislocations. It extends for hundreds of kilometers and represents a characteristic peculiarity of the floor relief of the northwestern part of the ocean.

It is a fact meriting our closest attention that on the floor of the Pacific Ocean, at an immense distance from the coast of land, there are simultaneously existing regions of complicated disjunction and perfectly smooth surface of the floor. This evidence refutes the earlier concept of an even covering of sediment smoothing out the original relief of the ocean floor or in some manner preserving its original unevenness due to an even covering. This is evidence of intensive processes of erosion and washout of the sediment cover taking place in the ocean deeps, of the displacement of masses of sedimentation material along the floor, and of the preeminent evening of the floor depressions on account of local sedimentation. It was noted before that the discovery of perfectly smooth deep-sea plains in the Atlantic Ocean caused a search for a special explanation of this smoothness. Under conditions existing in the Atlantic, the most likely cause of the even floor of basins should be sought in the turbidity currents which carry masses of sediment material from the region of the continental slope and thus fill the depressions in the floor. Under conditions of the Pacific Ocean, turbidity currents could play an essential role in smoothing the relief only in the eastern part of the ocean, where the zone of the continental slope abuts directly on the ocean floor /323 a/. In the remaining parts of the ocean, where the zone of the continental slope is separated from the ocean floor by deep-sea ocean

trenches which appear to be pitfalls for turbidity currents, the role of the latter in smoothing the floor surface seems to be doubtful. It should therefore be assumed that the relief-forming role of some other exogenic processes, for example of bottom currents or internal dislocations of sediment matter should be much greater than it was earlier assumed.

Investigation of small relief shapes widely distributed on the surface of the Pacific ocean floor shows that among them there is a prevalence of hills with isometric outlines. The immense depths at which these hills have been discovered, exclude, in the opinion of a majority of authors, the possibility of their subaeral erosive origin. It is difficult to explain the origin of the hills as due to bottom currents or any other exogenic processes under conditions existing on the ocean floor. A tectonic or volcanic origin of these hills seems to be the most probable /99, 176 a, 284, 285/.

A study of the laws governing the spatial distribution of small and medium shapes of the Pacific Ocean floor relief, made it possible to observe the following important features of the ocean floor relief. It was found that some sectors of the complicated relief stack up into a system of several linear zones, which are called shear zones. The character of the irregularities of the floor in the shear zones is quite varied: it possesses steep and high benches, underwater mountains and hills, deep and narrow trenches. Thus, for example, one of the shear zones

in the eastern part of the ocean, called the Mendocino zone, is characterized by a high (in some places up to 2,500 m) bench of great steepness (in places up to 30°), extending in a latitudinal direction for almost 2,500 km /321, 323 a, 326/. Other zones are noted for their narrow trenches and chains, as, for example, the shear zone discovered in the northwestern part of the ocean /349/ and the so-called Murray shear zone in the eastern part of the ocean. The combination of deep trenches and little chains of underwater mountains distinguishes the Clarion and Clipperton shear zones /323 a/. All shear zones are noted for their immense length. The shear system of the eastern part of the ocean also shows a remarkable parallelism of the separate zones and their extension of the continental boundaries of North America.

To sum up what has been said above on the results of the latest investigations of the Pacific Ocean floor relief, three special features can be noted. First of all, it is a prevalence of shapes of tectonic and volcanic origin in the relief. The Pacific Ocean flèer should apparently be regarded as a region of the greatest display of volcanoes anywhere on the earth. Further, the ocean floor relief shows signs of some regularities on a planetary scale which determine the direction and distribution of immense mountain structures, and the location of underwater volcanoes and shear zones. Finally, the development of deep-sea plains, along with the complicated floor relief

provides evidence of the variety of surface relief-forming processes in the ocean.

The individual sectors of the outskirts of the Pacific are very varied in their morphological properties. The relatively simple relief of the continental slope, similar in many details to the relief of the continental slopes of the Atlantic Ocean, is only applicable to the eastern part of the Pacific. Its western part, on the contrary, possesses an extremely complicated relief of the outskirts, representing an intermediate zone, and within its limits there are developed large mountain massifs combined with deep-sea ocean trenches on the one hand, and basins of the outlying seas, differing from the ocean, on the other hand.

Soviet oceanologists have conducted major operations of studying the underwater relief in the outlying seas of East Asia during the course of a number of recent years /29/. As a result of numerous expeditions of the Institute of Oceanology Acad Sci USSR on the expedition ship "Vityaz'" detailed bathymetric charts have been plotted showing the complicated relief of the intermediate zone. A study has been made of the relic relief of the submerged continental coast, providing evidence of considerable local submersions which accompanied the development of the intermediate zone /58, 96, 103/. Numerous, heretofore unknown underwater rises and ridges have been discovered and investigated within the zone of the continental slope. For example, a large underwater ridge has been discovered in the

Bering Sea. It is interesting that it is located exactly at the extension of the underwater Hawaiian ridge of the Pacific Ocean. It is possible that the ridge discovered in the Bering Sea is only the very northernmost end of the Hawaiian ridge, involved in the development of the intermediate zone and now separated from the Hawaiian ridge by the system of the Aleutian Island chain and by deep-sea trenches. The expedition on the "Vityaz'" discovered an outer underwater ridge of the Kurilles Island chain, and underwater ridges within the limits of the Kamchatka continental slope /6/.

The underwater valleys of the Kamchatka continental slope were subjected to detailed investigations; their shapes are on the same scale as the widely known underwater canyons of the California coast of the USA. A large number of heretofore unknown underwater volcanoes was discovered within the region of the Kurilles chain, which substantially complement the above-water system of volcanoes. Certain features of regularity can be discerned in the location of above-water volcanoes which could not have been noticed before without the data on the location of underwater volcanoes /8, 104/. Flat deepsea plains have been discovered on the bottom of the basins of outlying seas, separated from the ocean by the mountains of island chains. They represent, of course, the surface of sedimentation, accumulating in these natural cesspools. The peculiarities of their morphology are in many respects similar to the

floor relief outlines of the North Atlantic basins, and it is quite probable that the formation of these plains proceeds in an analogous manner under the action of turbidity currents.

The expedition on the "Vityaz'" paid particular attention to a study of a belt of deep-sea trenches associated with mountain structures of the intermediate zone. As a result of these investigations, the heretofore unknown true dimensions and configuration of the Kurilles-Kamchatka deep-sea trench were established. The morphological interrelationship between the Kurilles-Kamchatka trench and its neighboring Aleutian and Japan trench has been clarified, as well as between the Japan trench and the Idzu-Bonin trench to the south and the northern end of the Marianas trench. It was found that the Kurilles-Kamchatka trench is extremely long -- about 2,000 km. It joins the neighboring trenches -- the Aleutian and the Japan, forming together with them a huge ditch which extends along the western edge of the Pacific Ocean from the coast of Alaska to the Marianas Islands. The maximum depth of the Kurilles-Kamchatka trench is 10,542 m, i.e., it is close to the maximum depths of the Marianas, Philippine, Idzu-Bonin and other deep-sea trenches of the Pacific Ocean /98, 100, 104, 106/. It is possible that this similarity indicates some common rules of development governing the trenches. The Kurilles-Kamchatka trench has a characteristic V-shaped profile, and the steepness of its slopes reaches 10 to 15°. In the deepest part of the trench there is a narrow area of a flat

smooth bottom -- the width of this area is between 5 and 20 miles (i.e., from 9 to 35 km). This prèfile shape and the flat bottom are a common feature of all deep-sea trenches. The flat bottom of the trenches probably relates to the surface of the accumulating sedimentation. It is quite probable that the evenness of the trench bottom is associated with landslides and turbidity currents.

The expedition on the "Vityaz'" also investigated the relief of the western part of the Aleutian trench. In the region of the Komandorski Islands its depth reaches 7,000 m. The trench has very steep slopes: in places almost vertical benches were observed, 2,000 to 3,000 m high. Its bottom is also flat. The passage from the Aleutian to the Kurilles-Kamchatka trench does not show any perceptible threshold. The junction of the deeps represents a wide and even area, rising somewhat above the neighboring sectors, appearing as a widening of the flat bottom. The boundary between the Kurilles-Kamchatka and Japan trench is a little different; here we observe a relatively narrow and complicated forked threshold, above which the depth reaches 6,700 m, i.e., much more than above the abutting areas of the ocean floor, so that the region of great depths is not interrupted in the trench. Morphologimally, however, the threshold at the junction of the two trenches is quite clearly noticeable. The relief of the Japan deep-sea trench is similar to the relief of the Kurilles-Kamchatka trench: the same profile shape, approximately the same

steepness of slopes, and a flat smooth bottom.

A study was made of the system of deep-sea trenches extending sothward from Honshu Island along the Idzu, Bonim and Iwo Jima islands. Eearlier it was assumed that they all constitute a single unit with the Japan trench. Their course, however, quite sharply differs from the course of the Japan trench, which lies eastward from Honshu Island. They also differ from the Japan trench quite markedly by the nature of their relief, just as they do from the Kurilles-Kamchatka trench. The steepness of their slopes near the islands of Idzu, Bonim and Iwo Jima is not quite is great as in the Japan and Kurilles-Kamchatka trench, but the relief of the slope surfaces is mmch more complicated. The bottom of these trenches, although even, yet it is not quite smooth, and constitutes a series of separate cells. In the future it would be more expedient not to circulate the term Japan trench to include the trenches ndar the islands of Idsu, Bonin and Iwo Jima, since these trenches appear to us as independent formations, associated with the mountain structures of these islands. In addition, it seems to be incorrect to use the name Bonin with reference to the trench lying eastward of Iwa Jima, and separated by a high threshold from the trench which lies east of the Bonin islands. Since the trench near the Bonin islands is morphologically closely associated with the trench near the Idzu islands, it is more correst to regard both as a siggle trench and to call it the Idzu-Bonin trench. The trench near Iwo Jima might be comp-

ietely independent, and then it could be called the Iwo Jima trench, but as yet the problem has not been clarified concerning its association with or separation from the northern end of the Marianas trench. Perhaps it should be regarded as the northern end of the latter trench /9/.

If we assume this division of the deep-sea trenches in the western part of the Pacific Ocean, the maximum depths will be as follows: the Japan trench -- 8,412 m (according to the data of Japanese Chart No. 6901 /174/), the Idzu-Bonin trench -- 9,810 m (according to data of the "Vityaz'" expedition). The depth above the threshold separating the Idzu-Bonin trench from the Iwo Jima trench is 3,760 m.

The relief of the intermediate zone in the western outskirts of the Pacific Ocean was recently investigated by Japanese researchers /341, 342, 412/. Their main attention was centered on the relief of the coastal shelf and of the upper sector of the slopes of the mountain structure of the Japanese Islands /317/. Thus, detailed investigations of the shelf and of the upper slopes were conducted close to the coast of the island of Hokkaido; the results are shown on detailed bathymetric charts and in articles /99, 277, 286, 415/. Detailed studies were made of the underwater valleys on the slopes of the islands of Honshu and Shikoku /240, 341, 342/. Japanese investigations also embraced the region of the Idzu islands;

special attention was focussed on a study of the floor relief in the region of the Bayonnaise rocks where, in 1952, during an eruption of an underwater volcanoe, the Japanese research ship "Kayo Maru"5" was lost /266, 330/.

Investigations of the relief of deep-sea trenches at the western outskirts of the Pacific Ocean were recently conducted by a number of large oceanographic expeditions. Thus, for example, the expedition on the "Galatea" conducted detailed investigations of the Philippine trench, discovering the characteristic outline of its relief, peculiar nearly to all deep-sea trenches: a V-shaped cross profile, steep slopes, and flat smooth bottom /144, 280, 443/. As a result of the study of the Philippine trenhh bottom, a conclusion was reached as to its maximum depth; according to the data of "Galatea" it is 10,265 m, which is a little less than the depths of this trench indicated before /260/.

The investigation of the relief of the Japan and Izu-Bonin trench was carried out by the American "Trans-Pacific" expedition /210/. This expedition noted the essential differences in the course of the Japan trench and the Izu-Bonin trench, measured the great depths in the latter, and found that the bottom was flat and smooth. The British expedition on the "Challenger" studied the relief of the Marianas trench /153, 226/. The work of this expedition contributed to the discovery in the

Marianas trench, of a new maximum depth of the oceans of the world -- 10,863 m.*

The relief of the Tonga trench was studied in great detail by the "Trans-Pacific" expedition; a fairly detailed bathymetric chart of this trench has been drawn /361/. It should be noted that the "Trans-Pacific" expedition measured the greatest depth of the Southern Hemisphere in the Tonga trench -- 10,633 m**. The characteristics of its relief indicate that the Tonga trench is quite similar to the other deep-sea trenches of the western outskirts of the Pacific Ocean.

In recent years investigations were developing of the underwater relief in the southernmost outlying sector of the ocean, near New Zealand /137, 142, 248/. Information on the floor relief of this region is still quite scanty, but one of the first bathymetric charts has already been drawn on its basis /143/. The relatively shallow regions are most accessible to study, it is therefore understandable that the investigations of the floor relief in the New Zealand region were at first mainly concentrated on the explanation of the morphology of the continental shelf and of the upper part of the continental slope. Particular attention was drawn to problems of the association

* 11, 034 m according to datum 25 of the "Vityaz'" voyage.

** 10,882 m according to datum 26 of the "Vityaz'" voyage.

of the underwater relief with land structures and with some large glacial valleys /145, 214, 215, 216, 217/. Studies of small relief forms were carried out by New Zealand scientists in connection with the problem of the possible existence of land in the location of Cook Strait during the Quaternary period /418/. The published material on the floor relief in the neighborhood of New Zealand served as a basis of a concept of the origin of underwater canyons recently expressed by Cotton /160/.

The regions of the Pacific Ocean abutting on the Antarctic have been studied by various antarctic expeditions in the order of routine reconnaissance investigations /166, 172a, 233/.

The northeastern part of the Pacific Ocean, abutting on the shores of Central and North America was investigated in great detail. Expeditions of the Scripps Oceanographic Institute and of the Marine Electronics Laboratory of the US Navy conducted systematic studies of the underwater relief of the continental slope and of some regions of the ocean abutting on the continental slope. The rise of the Galapagos Islands was subjected to detailed investigation; it is located in the eastern part of the Pacific Ocean at the intersection of the underwater Carnegie and Cocos ridges /392/; in this regard it bears a familiar resemblance to the Obruchev rise which lies in the northwestern part of the ocean /99/. Hydrographic work made it possible to obtain detailed characteristics of the relief of the Guatemala deep-sea ocean trench, whose maximum depth equals 6,662 m. This is one of

the least deep trenches in the oceans, but at the same time it possesses the same relief features as the other deep-sea trenches of the Pacific Ocean: a V-shaped profile, an elongated contour, steep slopes, a flat and smooth bottom, and a wide bank at the edge of the ocean floor.

The continenal slope was studied in particular details at the shore of California, i.e., directly neighboring on the Scripps Oceanographic Institute which is located in La Jolla. The main object of the investigations were the underwater canyons of the continental slope and components of the relief which made it possible to determinedtheir association with the continental structure. The extent of work of studying the floor relief of the California coast, conducted up to date, is quite voluminous /419/. The scope of studies of the underwater canyons in this part of the ocean is probably the best, and the presentations of the California marine geologists concerning these problems /164, 385, 388, 389/ exert a considerable influence on the development of ideas of scientists in some other countries /160, 440/. The investigations of the deepest parts of the submarine canyons had the greatest effect on the development of ideas of their origin. It was found that the submarine canyons close to the California coast extend to the very foot of the continental slope and partially continue on the ocean floor; and the endings of canyons have peculiar deposit features /177/. In addition to the submarine canyons, the most

interesting features of the underwater relief off the California coast are numerous underwater ridges, rises and basins whose distribution indicates a close association with the structure of land. Thanks to these ridges, rises and basins, the continental slope in this area does not represent a steep bench, just as it does not represent a ~~steep~~ simple bench, judging from the data of the latest investigations, in other parts of the oceans, either. The investigations of this part of the Pacific Ocean have played a leading part in the development of ideas of the continental slope as an intermediate zone possessing a complex relief /190, 193, 307/.

The continental shelf off the California coast has been studied in considerable detail /192/. The data concerning its relief have made it possible to draw a number of important conclusions on the features of sedimentation within the range of the shelf, and on the association of the underwater relief with the tectonics of land.

Of great interest are the results of investigations conducted in recent years by the U.S. Coast and Geodetic Survey in the region of the Aleutian Island chain and the Aleutian deep-sea trench /228, 231, 331, 332/. Detailed large-scale bathymetric charts have been drawn from the material of these undertakings which show the extremely complex of varied relief of the underwater slopes of the mountain structure of the Aleutain ridge and trench. These charts are of particular interest in an analysis

of the association of the submarine relief with land tectonics, and particularly of the association of underwater valleys with break lines. The activities of American investigators in the northern part of the Pacific Ocean also embraced the Bering Sea /306/, where they obtained new data on the relic subaerial relief of the continental shelf /175/.

Investigations of the floor relief of the Indian Ocean were conducted on a relatively limited scale in the post-war period /209/. They consisted mainly of routine observations conducted by the round-the-world expeditions on the "Albatross," "Galathea" and "Challenger" /226, 280, 285/. The materials of these expeditions indicate a considerable complexity of the floor relief of the Indian Ocean, within whose limits we find vast submarine rises, individual isolated mountains, rolling plains and plains with a flat and extremely smooth surface. A number of submarine ridges forms a huge mountain system extending across the entire ocean approximately in the meridional direction. This mountain system resembles the Mid-Atlantic ridge in many respects. In particular, the slopes of the ridges indicate areas of flat plains located in depressions of the floor, resembling the "terraces" of the Mid-Atlantic ridge.

Materials of the investigations of the Indian Ocean floor relief remain mostly unpublished and have not been expressed on bathymetric charts. It is therefore difficult at present to speak of the appearance of concrete features of the floor re-

lief of this ocean in the light of the latest data. We can only speak of some of the most interesting peculiarities of the relief discovered in recent years. Thus, of great interest are the deep-sea plains discovered in the Indian Ocean, which are like the above-described plains of the Atlantic and Pacific Ocean Among these, the plain southwest of Ceylon, and another in the central part of the ocean are the largest in size. An interesting featuze of one of the dhep-sea plains abutting on the Bay of Bengal, are submarine valleys which are very similar to the submarine canyons in the deep-sea plains of the Atlantic Ocean. Since the origin of these canyons in the Atlantic Ocean is associated with the activity of turbidity currents, it can be assumed that they are of similar origian also in the Indian Ocean /174/. However, in the opinion of memy authors, the more probably hypothesis is the one on the tectonic origin of submarine valleys on the surface of the Indian Ocean floor /284, 285/.

A wide distribution of underwater mountains has been found in the Indian Ocean which have not been studied in such detail as the mountains in the Atlantic and Pacific Ocean, but according to available data most of them can be listed as underwater volcanoes. Underwater mountains are particularly numerous in the eastern part of the ocean. A detailed study of some would rather indicate their tectonic than volcanic origin /238, 350, 438/.

Detailed investigations were only conducted in limited regions of the Indian Ocean. Among these are the activities of

the French expedition on the "Calypso" in the Red Sea in 1951 and 1952 which made it possible to determine the tectonic origin of the principal relief features of the floor of this sea which represent a huge fault basin /336/. Investigations of the floor relief in the northernmost part of the ocean are being conducted on a more limited scale /299, 315/. These studies have apparently reached their largest scope in recent years close to the shores of Australia. The basic problems which interest the Australian scientists are problems of the association of the underwater relief with land tectonics /152, 208, 209/.

In the North Arctic Ocean the development of oceanographic investigations in the post-war period proceeded on the basis of wide utilization of aviation. Numerous air expeditions and a number of drifting stations investigated the floor relief. It must be admitted that until very recently the basic method of studying the underwater relief by arctic expeditions was the cable measurement of depth, and this method was replaced by the sonic method only since 1956. For this reason the relief of the North Arctic Ocean was not investigated in such detail as that of the other oceans where echo sounding is used for this purpose. However, the discoveries made in the North Arctic Ocean essentially change the former concepts of the relief of its floor, which had not been studied to a great extent. The data obtained are extremely important for an understanding of some laws governing the floor structure of the oceans.

Soviet high-latitude expeditions of the Arctic Scientific Research Institute of the Main Northern Sea Lanes have made a particularly large contribution to the study of the North Arctic Ocean floor relief. Such expeditions are conducted since 1946, by setting up drifting stations which make systematic investigations of the underwater relief along the drift route. The most important achievement of these expeditions was the discovery and investigation of a huge mountain ridge extending all across the North Arctic Ocean /74/ which was named the M. V. Lomonosov ridge. In connection with the discovery of the Lomonosov ridge, there has been a considerable change of the concept of the tectonics of the North Arctic Ocean /80, 86/. The discoveries made by the Soviet expeditions in the Arctic found many responses in foreign publications /156, 408, 409, 413/..

Investigations conducted by flying American expeditions in the North Arctic Ocean did not yield such important results as the Soviet expeditions, but they provide an essential supplement to the concept of the floor relief of this ocean in a sector abutting on the American North. Of particular interest is the information about the submarine canyons of the North Arctic Sea obtained by means of echo soundings made from drifting stations /156, 162, 162a, 163, 306, 447/. The work of Rex /364/ is dedicated to the problems of exogenous processes of the development of the submarine relief under Arctic conditions, and espeically of the activity of floating ice.

Investigations of the floor relief in the Antarctic Ocean in recent years were conducted on a widest scale by the British expedition on the "Discovery" /165/. This expedition investigated different regions of the Antarctic year after year and its materials provide a lot of information for an idea of the underwater relief of this ocean /249/. In addition to the "Discovery" the floor relief in the Antarctic was studied by American expeditions /172, 430/, and by a French Antarctic expedition /362/.

In 1956 a Soviet Antarctic expedition on the "OB'" /41, 59/ began a study of the underwater relief in the Antarctic. A survey of the history of the investigations of the Antarctic underwater relief and descriptions of the large mountain systems and basins have been given by Herdman, Wiseman and Ovey /252/. A bathymetric survey chart of the Antarctic has been composed by Kosack /288/. He also made an analysis and appraisal of all sources of original information concerning the depths of the Antarctic Ocean /287/. An article by Fleming /215/ is completely dedicated to a description of the Antarctic Ocean floor relief. More detailed descriptions of the floor relief of individual regions of the Antarctic are contained in the works of Kucherov, Fleming and Nares /41, 216, 335/.

In the light of the latest investigations the basic features of the Antarctic Ocean floor relief are conspicuous by the junction of several large mountain structures which divide the ocean into three large basins. The Atlantic-Antarctic

ridge extends in a latitudinal direction from the region of Tristan da Cunha islands to the region of the Crozet Plateau and bounds from the north the Atlantic-Indian Antarctic basin. The Kerguelen-Haussberg submarine range extends from the Kerguelen islands toward the Antarctic continent and abuts on it in the region of Drigal'skiy island. This ridge forms the eastern boundary of the Atlantic-Indian Antarctic basin. The Indian-Antarctic ridge extends from the region lying south of Australia toward the Balleni islands and bounds on the north and east the East-Indian Antarctic basin. Finally, the Pacific-Antarctic basin is bounded in the west and north by the Pacific-Antarctic submarine ridge, and in the east by the Southeast Pacific submarine plateau. The submarine ridge Macquarie-Balleni, extending from the southern end of New Zealand toward the Antarctic continent in the region of the Balleni islands represents a large relief shape of the Antarctic Ocean floor. The only deep-sea trendh of the Antarctic Ocean -- the South Sandwich -- is connected with the huge island arc of the Scott range which supports the groups of islands of South Georgia and South Sandwich and which abuts on the Antarctic continent in the region of Graham Land. The maximum depth of the South Sandwich Trench is 8,264 m /252/.

The surface structure of the continental shelf of the Antarctic continent is very complicated: it bears traces of glacial valleys and ravines, it is covered with numerous hills and

mounds, in a word it has the appearance of the shelves of regions of glacial covering. In some places the submarine border of the Antarctic continent in submerged to a great depth.

Ending this survey of regional investigations we must note that they have been only slightly reflected in the large published monographs on problems of marine geology and geomorphology /19, 35, 43, 118, 170, 289, 354/. The next several years will probably witness the publication of new works which will take into account all the wealth of material of the latest investigations. The latest data are sooner illustrated in charts and in atlases /3, 34, 68a, 130, 334, 442a/.

The development of concepts of the submarine relief calls for the development of terminology and nomenclature which would correspond to the new data. Thus, for example, in connection with preparatory work on the "Marine Atlas" a special manual "Marine Navigational and Geographic Terminology" /68/ was compiled in the USSR. Much work in this direction is being done by a special International Committee within the International Geophysical and Geodetic Union /252, 269, 440, 441, 442/. The problem of a genetic classification of the underwater relief /81/ should now be placed on a new level.

Fundamental Problems of Marine Geomorphology

In the course of regional investigations, special attention was paid to problems of the greatest general significance to the development of marine geomorphology as a science of the shape and origin of the underwater relief. A number of works of a general nature and separate survey articles have been dedicated to these problems and published in recent years /19, 35, 43, 78, 79, 118, 289, 439/.

The list of the most interesting general problems of marine geomorphology is quite large. It includes problems of the origin of such large relief shapes as the ocean trenches anf of large shapes which developed against their background, as well as the huge variety of small shapes which were formed on the surface of the largest and largest shapes. The opinions on the process of contemporary relief formation and on the dynamics of the underwater relief are of major interest. Problems of the history of the relief are also extremely interesting, since they reflect the past stages of the development of the seas and oceans, and particularly of the Quaternary age, with an explanation of the effect of eustatic oscillations of the ocean level on the development of the underwater relief.

One of the most important problems of marine geomorphology, which simultaneously extends beyond its scope and is rather a part of the science of the earth -- is the problem of the origin

of the continents and oceans. Methods of marine geomorphology might contribute much to the solution of this problem. The following problems fall within marine geomorphology: the causes of the formation of continental rises and ocean trenches, the direction of the growth process of these largest relief shapes of the earth's surface, their age and structural relationship, which determine the nature of the large relief shapes.

New data on the structure and strength of the earth's crust, obtained by gravimetric and seismic research /37, 61, 133, 134, 135, 202, 232, 237, 258, 359, 416, 429, 446/, are most important for an understanding of the present state of the problem of the causes which produced the continents and oceans. In the light of new data we cannot imagine the origin of the continents and oceans otherwise than as a result of radical and profound differences in the strength and structure of sections of the earth's crust. Continental rises correspond to regions of the earth's crust with a thick granite-sedimentary cover averaging 35 km. Ocean trenches occur over regions of the crust without a granite cover, but with a relatively thin basalt cover, averaging 5 km, overlaid with a stratum of unconsolidated sediment about 1 km thick. Thus, the problem of the origin of the continents and oceans can be reduced to the problem of the origin of the granite (sial) layer of the earth's crust which, according to a majority of investigators, was formed as a result of a differentiation of the earth's plutonic substance. This viewpoint

follows from the present concept of the structure of the earth's crust, and is a determinant of the uniform opinion regarding the causes of the origin of continents and oceans expressed by a majority of authors in recent years /11, 12, 13, 14, 15, 115, 116, 202, 203, 258, 278, 308/.

Another important question in the problem of the origin of continents and oceans concerns the direction in which the development of the granite layer of the earth's crust proceeds. Among the variety of opinions expressed on this subject, there are two basic groups with two viewpoints. According to one, the development of the sial cover corresponds to the general direction of the earth's development, manifested in the generally irreversible decrease of the area of synclinal regions, and in the accretion of platforms /117/. Here the formation of the granite layer and of the continental rises is presented as a "summary result of the appearance and development of geosynclinal systems, migration of foldings and volcanism, and of a gradual transformation of geosynclinal regions into tectonic platforms" /40/. This viewpoint, with certain variations, is maintained by a number of authors /17, 62, 63, 75, 258, 278/. This viewpoint is opposed by the concept which states that there is no straight direction in the formation of the granite layer, and that the existence of the continents and oceans does not depend on the presence of geosynclinals and platforms on the earth /11, 12, 13, 14, 79/. According to the latter viewpoint, there is a

possibility not only of a gradual and successive increase of the granite layer, but also of a reverse process of disintegration and destruction of this layer in large areas, and consequently, the submersion of former continents and the emergence of new oceans. It should be noted that a partial disintegration and a well-known regression from the general straight direction of the growth of the granite layer is admitted even by the adherents of the first viewpoint. However, the size of such regressions, according to their opinion, should be insignificant, and should not encompass large areas of continents.

In accordance with the different opinions expressed in connection with the direction of the process of formation of the granite layer, there are also concepts of the age of the oceans, peculiar to each different group of authors. Thus, according to the concept of the straight direction of the development of the granite layer of the earth's crust, ocean trenches are old formations in a major part of their area, and their surface had never been land. The occasional disintegration of the granite layer could cause the submersion only of some borders of oceans /40, 61, 202, 203/. The problem of the age of ocean trenches is differently solved by the adherents of the concept of the disintegration of the granite layer in large areas of the earth which began in the Mesozoic. According to these concepts, all ocean trenches are new formations /11, 12, 13, 14, 15, 79/.

In addition to these extreme viewpoints, a concept has been

developing in recent years of the possible formation, along with the old or primary oceans, or nuclei of oceans, also of younger, secondary oceans, or of sufficiently large secondary parts of oceans /63, 71, 114, 115, 116, 403, 404/. It is assumed that the disintegration of the granite layer of the earth's crust is the cause of the formation of secondary oceans.

The concepts of the tectonics of continents and oceans are an important result of a different solution of the problem of the direction of their development. From the position of the adherents of the idea of a straight direction of development, the ocean floor should be considered the remainder of the primary earth crust which was never subjected to an intense folding and mountain formation /40, 81/. From this viewpoint the structures of the continents and oceans cannot be the same and cannot change one into the other. On the other hand, the concepts of the changing direction of development brings their adherents to the conclusion of the unity of the structures of the continents and oceans, of a direct extension of the continental structures into the ocean areas, and of a development on the ocean floor, of the same kind of complex of tectonic phenomena as on the continents, but merely at a lower hypsometric level /11, 12, 13, 14, 15, 77, 78, 79/.

The problem of the tectonics of the floor of the oceans and seas, albeit extending beyond the scope of naturally geomorphological problems, nevertheless the data of marine geomorphology

undoubtedly play an important part in its solution. A comparison of the structures of land with those of the ocean floor is possible thanks to the peculiarities of the development of the underwater relief: the transformation role of exogenous processes under conditions of a water medium is not so great as to deprive the structures of the bottom of the seas and oceans of surface features. An analysis of small relief shapes makes it simultaneously possible to determine the direction in the development of large shapes, on top of which the small shapes are located. All this makes it possible to draw conclusions as to the existence or absence of unity between the structure of land and of the ocean floor, as to the similarity or difference in the direction of their development, and as to the link between some land structures and structures concealed under water.

A number of articles published in recent years is dedicated to the problem of the role of tectonic movements in the formation of the relief of the earth's surface, including the underwater relief /72, 82, 83, 83a, 114, 115, 116, 132, 133, 159, 258, 404, 445/. Numerous works are dedicated to the problem of concrete links between the underwater relief of some sections of the oceans with the structures of the abutting land /23, 36, 38, 39, 69, 70, 80, 86, 90, 101, 103, 104, 108, 119, 142, 152, 181, 182, 209, 215, 228, 231, 257, 260, 275, 336, 369/. The basic result of a majority of the above works consist of conclusions as to the extension of definite land structures into the

limits of the continental shelf and continental slope, and of the association of some shapes of the ocean floor with structures that are connected with land structures. In recent years works also appeared which are dedicated to a tectonic interpretation of the submarine relief of large areas of the open ocean that are in lesser degree associated with land in the structural sense and which posses tectonic features on a very large, even planetary scale /174, 204, 257, 259, 285, 321, 322, 323, 326, 349/. There are particularly interesting conclusions regarding the existence of linear zones of tectonic breaks in the Pacific Ocean which extend over immense distances to the borders of the North American continent /323/.

Successful development of the concepts of the tectonic relief of the floor of oceans and seas was determined not so much by advances in the field of technique and method of investigation, as by the general sweep of work during the postwar years. In order to have an idea of the tectonics of the floor of oceans and seas it is first of all necessary to have a correct idea of the large relief shapes of the floor, which is accomplished on the whole by a dense network coverage of aquatoria with measurement stops, i.e., by the intensity of work.

In the development of concepts of the surface relief-forming processes, advances in technique and method of investigations played a decisive role; it was the foundation of all achievements in this field. Acutally, in order to judge the nature of

exogenous relief-forming processes, first of all data are required on the small shapes of the underwater relief -- they became accessible on a sufficiently large scale only in recent years, thanks to a number of improvements in the design of echo sounders and in the method of their operation, which were mentioned in the first chapter of this article.

In addition to works dedicated to certain general problems of contemporary exogenous relief formation on the bottom of the oceans and seas /103, 108, 200, 284, 386, 401/, studies have also appeared with reference to individual relief-forming processes. Works by the following authors were dedicated to problems of the relief-forming role of ocean swells: King /281/, Kuenen /295/, Manohar /316/, Menard and Boucot /324/, and Dietz and Menard /175/. The problem of the relief-forming role of bottom streams which had been very inadequately developed in previous years, is now illustrated in numerous articles, based on materials of the latest investigations /176a, 206, 270, 340, 343, 347, 363/. Most of these articles are noteworthy for their insistence on the important relief-forming role of bottom streams, earlier underestimated due to the lack of correct concepts of the actual speeds of bottom movements of water /118/.

The problem of formation of the microrelief as a result of the activities of marine animals is examined in the article by Emery /189/, and as a result of the movement of ice, in the article by Rex /364.

The problem of the relief-forming role of submarine landslides which had been getting the attention of investigators of the ocean floor for a long time, has been developed in recent years in the works of Kuenen /296/, Mitchell /328/, Shepard /390/, and others. Submarine landslides as a cause of turbidity currents, constitute a concept worthy of attention /242, 243, 289, 296/.

The consequences of a submarine earthquake which took place in the Grand Banks area in 1929, were the subject of a number of investigations. This earthquake produced a submarine landslide which was accompanied by breaks in underwater telegraph cables. The instants of the breaks which were recorded with considerable accuracy, made it possible to determine the details of the development of the landslide and its change into a turbidity current, moving over the surface of a nearly horizontal ocean floor. This current possessed such a large power, that it caused breaks in its turn, and carried them over great distances into open areas of the ocean. The broken cable which were found and the nature of marine deposits in the area over which the current had spread -- all this definitely confirmed earlier assumptions of the nature of processes which take place during the movement of turbidity currents /173, 194, 200, 201, 300/. It was definitely established that turbidity currents were capable of carrying deposit material of relatively great thickness over great distan-

ces, into the range of deep-sea parts of oceans. The deposits c the turbidity currents are characterized by a diminishing grain size along the vertical, within the limits of the layer. Turbid ty currents, at certain stages of their development, are capabl of eroding the surface of sediment layers which had earlier bee deposited, and then to smooth the unevenness of the primary relief, filling in the depressions with carried material. At the present time, the formation of peculiar valleys with mainstream benches, deep-sea plains and flats on the bottoms of deep-sea trenches, as well as sections having a flat surface of the floo on the slopes of underwater mountain ranges, are associated wit the activities of turbidity currents /14[illegible], 195, 196, 197, 244, 246, 290, 291, 292, 293, 297, 298, 309, 327, 387, 428/.

In connection with the problems of the latest history of the seas and oceans, there is much interest in the new data on the existence, on the bottom of the sea, of a sunken relic coastal and subaeral relief /56, 58, 96, 103, 234, 355, 356, 357, 362, 381, 410/. The cause of the submersion of the relief of this type to its present depths could have been either eustatic fluctuations of the level of the ocean, or differentiated tectonic movements /32, 54, 55, 72, 10[illegible], 207/. The preservation of the relic relief under conditions prevailing on the ocean floor is considered to be the result of specific circumstances of sedimentation in some zones /33, 53, 58, 96/.

The problem of fluctuations of the level of the oceans gave rise to an extremely voluminous literature. However, the geomorphological side of this phenomenon has thus far not been studied with sufficient thoroughness. A number of articles which were published in recent years, refer to the question of the role of eustatic fluctuations of the level of the ocean in the development of the relief /198, 207, 213, 294, 318, 384, 388, 391, 398, 418/.

There is quite a large number of problems associated with the problem of the continental shelf. These problems are divided into two fundamental groups: 1) the origin of the continental shelf as a definite geomorphological surface, and 2) the origin of the relief within the limits of the continental shelf. The origin of the continental shelf, a geomorphological surface of considerable dimensions, is believed to be the result of the sinking of the borders of continents, according to a majority of authors /19, 78, 81, 118, 289/. Alongside this viewpoint, opinions are also expressed of the need to separate two different surfaces within the limits of the continental shelf as a whole, according to the nature of the relief: the coastal, representing a surface of an abrasive-accumulating smoothening, and the exterior, preserving the character of the subaeral relief of the continent's borders in a little-changed shape /65, 106, 172, 17[illegible]a, 401, 433/. The formation of such a sizable surface of an abrasive-accumulating smoothening

as the coastal section of the continental shelf is considered to be the result of the migration of the zone of wave activity during the process of the rise of the ocean level in the post-glacial period. The more deeply sunk part of the continent's border was not subjected to the effect of this migration of the wave zone, and consequently it preserved its original relief in a less transformed shape.

The configuration of the continental shelf and some peculiarities of its relief as a whole were compared by a number of authors with the peculiarities of the tectonics of land. As a result of this comparison, a correspondence between the basic features of the relief of the shelf and the structures of the land was observed in a number of instances /141, 152, 154, 155, 192, 302, 307, 369, 415, 434/. The character of the small relief shapes, noticeable within the limits of the shelf, as well as the origin of its clearly expressed external border, is associated with the peculiarities of the abrasive-accumulating smoothening during the process of the rise in the level of the ocean /172, 175, 337, 400/. The relic subaeral relief of the shelf has been described from material of the most recent operations in articles by Bruun /145, Elliott, Myars and Tressler /187/, Murray /333, Pratje /356, 357, and Stocks /410/. The nature of present-day sedimentation within

the limits of the shelf and the effect of this process on the the development of the shelf relief is the subject of articles written by Price /360/, Stetson /399, 402/, Rutten /370/, and Tricart /423, 424/.

In recent years the problem of the continental slope has also been quite logically subdivided into two groups: 1) the origin of the continental slope as a whole, treated as the transitional zone between the continent and the ocean; and 2) the origin of relief shapes within the limits of this transitional zone. There are plans to change from the earlier, undoubtedly simplified concepts of the continental slope as a bench separating the continent from the ocean bed, to the more correct concepts based on materials of the latest investigations, i.e., of the continental slope as a complex transitional zone. Many author believe that the relief of the transitional zone reflects not only the hypsometric differences between the surfaces of continents and the ocean bed, but also the essence of the geological structure of the transitional zone from sectors of the continental crust to oceanic sectors, which differ both in thickness and in structure /40, 72, 73, 115, 116, 349/. It was found that the relief of the contineantal slope is much more complicated

than it was earlier assumed, and that instances of a relatively simple bench are rather the exception than the rule /172, 200, 229, 274/. It has also been proved that the relief of the continental slope reflects the nature of the tectonics of the abutting land and shows a connection with its structure to a greater degree than the flattened areas of the continental shelf /103, 192, 193, 307, 434/.

A number of works completed in recent years, are dedicated to the exogenous processes of the relief development of the continental slope. They explain the peculiarities of relief formation on the continental slope, which consist of a intensive activity of bottom currents, with an important role played by landsliped and turbidity currents /4, 103, 229, 274, 343, 390, 437/.

The problem of submarine valleys and canyonssis closely associated with the problems of continental shelves and continental slopes. A great deal of light was shed on this problem at one time in connection with the world-wide discovery of submarine valleys and ceanyons /16, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 76, 118, 289/. The cause of this increased interest in problems of the origin of submarine valleys and canyons lay in the circumstance that the hypotheses of their erosive origin gave rise to the assumption of grandiose fluctuations of the ocean level in very recent times, and made it possible to explain a number of the most difficult problems of paleogeography in the light of these assumptions /52, 53, 384, 388/. Later, however, as a

result of more careful, detailed and responsible investigations, it was found that the erosive appearance applies only to the very topmost parts of submarine valleys and canyons /76, 341, 385/. It became clear that along most of their extent, a majority of canyons and valleys do not possess any features of erosive valleys; simultaneously much data appeared indicating an association of the valleys and canyons with the tectonic features of the abutting land, which made it possible to detect in them shapes of tectonic origin /43, 103, 104, 156, 159, 164, 228, 231/. New data on the subject of the relief-forming role of submarine landslides and turbidity currents are very important to an understanding of the nature of submarine valleys and canyons /146, 173, 177, 195, 201, 323, 344, 390/.

Following the amassing of new facts, the concepts of the origin of submarine valleys and canyons rapidly changed, becoming more complete and complex. The initial interest in the hypothesis of the subaeral origin waned, and new views replaced it. The attempts to provide a univeraal explanation of all features of the morphology of submarine canyons were embodied in the so-called Shepard composite hypothesis /389/. According to this hypothesis, the origin of submarine canyons is associated with the activity of subaeral river erosion and turbidity currents. This hypothesis does not as yet permit the assumption of a possible existence of canyons of different origin in nature, but simultaneously it states that different parts of canyons owe their origin to dif-

ferent processes. Dividing submarine canyons into three basic parts, Shepard gives the following explanation of their origin. The middle or main part of a canyon, the most deeply cut and possessing steep rocky slopes, was produced by subaeral river erosion in a relatively remote past, when the region of the present continental slope still consisted of an above-water edge of the continent, not as yet submerged under the ocean level. In its present condition this part of a canyon is saved from being buried under marine sediment thanks to the action of submarine landslides and turbidity currents which remove the sediment from the canyon. The upper part of a canyon, bearing marks of recent subaeral development was produced as a result of river erosion relatively recently, during the low level of the oceans in the Quaternary Ages of glaciation. The lower part of a canyon was produced as the result of submarine landslides and turbidity currents, and represents either a landslide fault or a canal of a turbidity current dug in the porous layer of marine sedimentation, forming an alluvial train or fan at the foot of the continental slope.

Unlike the Shepard hypothesis, the new Kuenen hypothesis /292/ takes into account the possibility of the formation of two different types of submarine canyons which differ by their morphological features. The first type of canyon which Kuenen calls the Corsican, represents erosive river valleys flooded as a result of a considerable sinking of the land. The second

type of canyon is produced as a result of the active erosion of rocks of the continental slope by turbidity currents. Kuenen calls this type the New England canyon. According to Kuenen, the most typical examples of the two types of canyon are those off the shores of Corsica and close to the shores of New England (North America), respectively. Kuenen, however, does not mention the possibility of an even greater variety of types of canyons and the possible causes of their formation. For this reason we believe that the opinions of Cotton constitute a forward step: he thinks that it is possible to speak of different types of canyons and to assume several possible causes of their origin, depending on local conditions and on the history of the development of the continental slope /160/. Cotton pays special attention to the undoubtedly wide distribution of canyons of tectonic origin, similar to the canyons off the shores of New Zealand.

There is a sufficient amount of data available at this time to cease thinking of submarine canyons and valleys as structures of a completely identical morphology. On the contrary, judging by factual material, the morphology of submarine canyons and valleys substantially differs, and they possess specific local features in different regions of the oceans. It is therefore natural to assume that the causes of the formation of submarine valleys and canyons could have been different in different regions, just as the geological history of various sectors of continental

differs in many regions. Along with this, the most concrete factors in the formation of submarine canyons under different conditions are: tectonic dislocations, subaeral erosion with subsequent submersion of river valleys both as a result of differentiated tectonic movements, as well as eustatic elevation of the ocean level, submarine denudation and erosion by submarine landslides and turbidity currents. The fact that submarine valleys and canyons have preserved a clear morphological appearance seems to us to be associated with a more common process to all of them: erosion due to bottom streams, landslides and turbidity currents. Different combinations of all these causes and development factors, which depend on local conditions and on the geological history of each specific region, produced this variety of shapes and types of submarine valleys and canyons which we observe at the present time.

There is quite a large number of questions associated with the problem of huge mountain structures, island chains which are often referred to as island arcs, and deep-sea trenches attached to them. The importance of the problem also reaches beyond the scope of marine geomorphology, just as tnat of the problem of continents and oceans. The problem here mentkoned is part of the group of the greatest problems of modern geology, since it points the way to the solution of a number of important theoretical questions of this science /25, 26, 27, 28, 117/. However, the data of marine geomorphological studies are probably even of

greater importance to the development of the problem of island chains and deep-sea trenches.

The study of the submarine relief of island chains and deep-sea trenches was limited by the technical possibilities of deep-sea investigations for a long time, by thanks to the improvement of echo sounders and of their operation, it has made great forward strides in recent years. Considerable contributions toward an understanding of the morphology of deep-sea trenches and island chains were made by the above mentioned works of Soviet expeditions in the "Vityaz'," by the foreign expeditions on the "Galathea" and "Challenger," and by the expeditions of the Scripps Institute and Woods Hole Institution. In recent years there has been a continuously growing interest in the study of island chains, and scientists of many nations have been concentrating on the study of this interesting subject /4, 6, 8, 28, 29, 98, 100, 101, 104, 106, 144, 145a, 153, 199, 200, 210, 226, 228, 231, 241, 266, 275, 277, 280, 285, 286, 330, 331, 332, 345, 355, 361, 443/.

Material on the morphology of mountain structures of island chains and of deep-sea trenches attached to them makes it possible to speak of them as very peculiar morphological complexes. The term "island arcs" which is frequently applied to them is not quite correct: a raihbow-shaped form in not quite indicative of them, and in a number of cases it is not even applicable. In our opinion, the indicator is precisely the junction

of two large shapes in a single complex: the mountain structure of the island chain and the deep-sea trench. There is an additional important circumstance: in most cases this morphological complex is part of an intermediate zone between the continent and the ocean. It is also necessary to point out that there are such typical features of morphological peculiarities as the connection of volcanic structure with the internal ridges in the case of double chains. The slopes of mountain ridges of island chains and of deep-sea trenches are very steep and they are made even more complicated by steeper benches and gentle steps which separate them. There is a very characteristic complex division of mountain slopes of the island chains and deep-sea trenches by submarine valleys and canyons. It is interesting that the nature of the divide is different on the continental than on the ocean side. In every case the trench bottom is a narrow strip of a flat plain produced as a result of the accumulation of sedimentary deposits.

Much data available at the present time indicate a close association of island chains and deep-sea trenches with the depth structure of the earth's crust /60, 117/. There is ample reason to speak of these morphological complexes as reflections of the structure of the earth's crust characterizing the intermediate zone which are caused by the development of deep fissures /83, 83a, 132, 133, 134, 135/.

A number of signs which are representative of geological

conditions in deep-sea trenches and island chains, make it possible to regard them as present-day synclinal zones /4, 5, 9, 22, 27, 67, 101, 117/. Some authors believe that present island chains and deep-sea trenches are direct analogies of geosynclinal zones of the past and represent a definite stage in the development of the earth's crust /42/

The problem of the greatest depths of the oceans is actually quite different from the above-mentioned fundamental problems of marine geomorphology: it is not associated with the origin of kind kind of shape or another, but with the purely morphographic features of the ocean floor. This problem, however, is also interesting in connection with the problems of the origin of submarine relief, since, in final analysis, it makes it possible to approach the idea of the general extent of fluctuations of the earth's surface. Magnification of the power of echo sounders and improvement of the method of depth measurement have made it possible in recent years to revise some maximum depths of the ocean (trenches), to correct them, and to discover new and heretofore unknown depths /111, 259, 405, 407, 449, 450/. At the present time the greatest ocean depth in the world is the depth of the Marianas Trench: 11,034 m /153, 226/. This is also the greatest depth of the Northern Hemisphere, while the greatest depth of the Southern Hemisphere lies in the Tonga Trench: 10,882 m /210, 212/, as indicated above. It should be noted that both depths are in the Pacific Ocean. The greatest depth in the Atlantic

Ocean is 9,199 m according to Lyman, and it is located in the Puerto Rico Trench /312/. The most reliable sources, however, indicate that the maximum depth in the deep-sea trench of Puerto Rico is only 8,381 m /199, 345/. The greatest depth in the Indian Ocean is in the Java Trench and equals 7,450 m /280/. It is possible that the amplitude of the greatest cave-in of the earth's crust is approximately equal in all deep-sea trenches of the oceans. This is indicated by the striking similarity of the depths of the deepest trenches. The differences in the depths of some trenches can be explained either by variations in the stages of cave-ins or by differences in the thickness of the sediment layer which accumulated at the bottom of the trenches to the present time. Data of geophysical investigations indicate essential differences in the thickness of porous marine deposits which accumulated ay the bottom of the trenches /361, 393a/.

Widely distrubuted isolated underwater m[illegible] are discovered on the ocean floor in recent years. The discoveries caused the appearance of a number of works concerning their origin and role in the ocean floor relief. In some instances the investigation of the floor relief on underwater mountains makes it possible to regard them as large block rises /238, 285, 350, 438/. In other cases, which constitute a majority, investigations indicate that underwater mountains possess the shape of a regular cone or frustum which were formed as a re-

sult of submarine volcanism. Investigation of specimens of crust rocks and gravimetric tests also give reason to speak of a volcanic origin of submarine mountains, and this concept has recently found wide endorsement /57, 190a, 245, 247, 252, 256, 301, 323a, 338, 441, 448/. Paleontological investigations of coral fragments and foraminifera collected on the tops of some underwater mountains in the Pacific and Atlantic Ocean make it possible to refer the time of the formation of these mountains to the Cretaceous period/174, 200, 239/.

Students of the underwater relief are very interested in problems of the origin of deep-sea plains and small relief shapes of the ocean floor. The cause of this interest lies in the fact that the formation of these shapes cannot be explained in the light of the earlier concepts of exogenous processes of relief development at great depths. The discovery of these shapes gave rise to the development of concepts of the existence of powerful exogenous factors of relief formation which had not been taken into consideration before. One of these factors appears to be the turbidity currents whose existence is clearly proved in the Atlantic Ocean and in the Eastern Pacific. However, the action of turbidity currents cannot serve as an explanation of the origin of some deep-sea plains in the Western Pacific Ocean which are separated from the zone of the continental slope by a deep ditch -- a chain of deep-sea trenches. Consequently, next to be considered is the problem of explaining the role of other exo-

genous factors in the development of these deep-sea plains, possibly bottom streams or intra-stratum dislocations of sedimentation substances. Much remains to be explained in the problem of the origin of small relief shapes of the hill or hillock type, as well as trenches and valleys on the floor surface of the Pacific Ocean. For the time being, it seems most probable that the origin of these relief shapes is associated with volcanism and the result of tectonic dislocations. However, a completely definite solution of this problem can only be obtained as a result of deep-probing investigations resulting from a detailed study of the ocean floor relief aided by geophysical observations, and primarily by experimental seismology methods which would bring to light an association of the shapes of the ocean floor relief with structures.

The use of new devices and methods of investigation and the extraordinary sweep of studies of the ocean floor relief during the course of the International Geophysical Year open up great prospects and avenues of new achievements in gaining knowledge of the submarine ocean relief.

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SEISMIC INVESTIGATIONS IN THE SEAS AND OCEANS

(A Survey)

by Yu. P. Neprochnov

Marine Seismic Investigations Abroad

United States of America. Marine seismic work was begun in the United States in 1935 by the Woods Hole Odeanographic Institution under the direction of M. Ewing. Systematic geophysical investigations starting with observations of the coastal regions of the Atlantic Ocean south of Woods Hole and east of Cape Henry. In this preliminary work /21/, refracted and reflected waves were received by seismographs (geophones) which were lowered to the bottom from an anchored ship. In work by the method of refracted waves explosions on the ocean floor were set off from a small whaleboat which sailed away from the recording ship to a distance of up to 8 miles. In order to eliminate accidental interference, reception was usually simultaneously taken by two geophones, lowered from different decks. A third geophone was used to record the direct waye passing from the exolosion through the water. The distance to the point of

the explosion was calculated by the time of the reception of this wave. Finally, for the purpose of recording the water wave, a pressure receiver or hydrophone was used. In work by the method of reflected waves, the recording was made on three geophones, lowered to the bottom from the bow, midsection, and stern of the ship. The authors point out that this method was used in regions up to 180 m deep.

This work was continued in 1936 /23/, and seismic investigations by this method were conducted in many shallow regions (depths from 18 to 36 m): in Chesapeake Bay, Jacksonville near Florida, the Virgin Islands, Barbados, and in the Orinoco Delta /24/. The most valuable results were obtained by the refracted wave method. The thickness of the crystallic covering of the foundation was determined in all locations. The data of the reflected wave method, due to difficulties of correlation (observation points were located at distances of several miles from each other) basically served as supplementary material.

Simultaneously with the work in shallow regions, experiments were conducted at great depths of the Atlantic Ocean. In the initial variant, a cable was lowered from the ship to the bottom, and attached to it was a four-channel oscillograph and four seismographs at distances of 120 m from each other, and then three bombs were placed every 300 m /22/. This equipment was very bulky and frequently went out of order due to mechanical defects. Therefore, it was subsequently replaced with

floating equipment /22, 24/. The recording apparatus (seismic receiver and oscillograph) was placed in a hermetically sealed housing and was lowered to the bottom together with a gasoline-filled tank and ballast. Explosions were also set off on the bottom. After recording the explosion, a special device would uncouple the ballast, and the apparatus floated to the surface. Special methods were developed of calculating the instant of detonation and the distance from the place of the explosion to the receivers by the entrance of the direct water wave and by reflections from the surface and bottom of the ocean /10/.

World War II interrupted the seismic investigations at this stage. However, in spite of the fact that the activities during those years were primarily for a military purpose, during their course much important material for seismics was obtained: good knowledge was gained of phenomena which took place during underwater explosions, and of the laws governing the propagation of sound waves in the water. One of the most important achievements was the discovery of the possible use of pressure receivers -- hydrophones /51/ in marine seismic work.

By 1946 hydrophones were successfully used as seismic receivers in work by the refracted wave method in Bikini Atoll /18, 19/. A method of shooting through was used, with fixed receivers at the ends of long lines, with the explosion point between them being changed. An additional hydrophone was

used to receive the direct wave proceeding from the explosion in water, it was sensitive for frequencies of 50 to 1,000 cps, while at that time most hydrophones were working at frequencies between 1 and 200 cps. In these investigations the hydrophones were placed on the bottom.

Seismic investigations were revived in the Atlantic Ocean during the postwar years. In 1946 to 1947, the Woods Hole Oceanographic Institution together with the Geological Department of Columbia University conducted wide investigations by the reflected wave method between New York, the Bermuda Islands, Puerto Rico, the Greater Antilles, the Bahamas and the east coast of the United States /7, 32, 32a/. All observations were made from one ship. Serving as a receiver was a hydrophone with a Seignette's salt crystal whose outlet was fed into an amplifier through a graduated separator and an octave band filter. The amplifier had a horizontal performance at frequencies from 100 to 5,000 cps. The recording was made by photography from an electronic oscillograph. The hydrophone was lowered to a depth of 50 to 300 m, but lesser depths were preferred because then the recording was less complicated. In the first stage of work explosions were set off at depths from 30 to 100 m, and then at depths from 0.5 to 1.0 m. Usually, at each station several explosions were recorded at different positions of the octave filter. Satisfactory recordings were obtained within

the frequency range of 150 to 300 cps, and good recordings at a frequency of 75 cps were only obtained toward the end. In addition to depth reflections, recordings were made of a series of reflections from the surface and bottom of the ocean. Separation of useful reflected waves was mainly obtained by frequency peculiarities: they were recorded at relatively low frequencies in comparison with waves which had many reflections in the layer of water. The basic reflecting level was traced to a depth of about 200 m below the ocean floor.

In 1948 work was resumed by the refracted wave method in the submerged Atlantic coast plain in the region of the continental shelf and continental slope /16, 25/, with simultaneous investigations in the deep-sea trench of the Atlantic Ocean /26, 30/. The work was conducted by the Woods Hole Oceanographic Institution and by the Lamont Geological Observatory of Columbia University. With regard to method, these investigations can be divided into two directions, principally determined by the ocean depth.

In coastal regions, up to depths of 100 to 150 m, where ships can stay at anchor, seismic receivers are lowered to the bottom. The usual seismographs (geophones) as well as hydrophones were used as seismic receivers /25, 48/. Seismic receivers were connected with the inputs of several amplifiers with different filters. For the reception of refracted waves

amplifiers were commonly used which were sensitive to frequencies of 2 to 120 csp; ocean waves were received on high-frequency filtration. The recording ship remained stationary during the work, and explosions were set off at definite intervals on lines. The charges were placed on the bottom usually, or at lesser depthsę when the cable was too short. In the latter case the depth of the explosion was determined by the pulsation period of a gas bubble. The instant of the explosion was communicated to the recording ship by radio. When explosions were set off from whaleboats, the length of lines was not more than 7 to 10 miles for the sake of safety. Oppositel hodographs of refracted waves were obtained on all lines, which ensured identical interpretation. The accuracy of the work corresponded to the reconnaissance survey. In this manner profiles were processed, overlapping along three lines of the continental shelf off Cape May, New York and Woods Hole /25/, eleven profiles in the Long Island region /48/, and two mutually perpendicular profiles near Ambrose lightship /15/. As a result of this work, a determination was made of the occurrence of the depth of the crystal foundation covering, and the sediment layer was divided into two strata, called the "unconsolidated" and "semiconsolidated" deposits.

The shortcomings of the above-described methods (few operations, limited length of profiles, etc.), stimulated the application of more convenient methods of seismic investigations in the relatively shallow regions of the continental shelf, such

as had been developed for deep-sea regions. Thus, in 1950 to 1951, profiles were investigated along two lines near the Gulf of Maine /20/, several profiles south of Nova Scotia from the coast to the deep-sea trench /46/, and seven reconnaissance profiles in the Grand Banks regions /11/. Along all these profiles determinations were made of sedimentary rocks' thickness and of the speed of seismic wave propagation in deposits and in the crystalline foundation.

A detailed description of the method of deep-sea seismic investigations by the refracted wave method in the Atlantic Ocean was given in several works /26, 33. 47/. In the study of the submarine geology of the Bermuda Islands region in 1950 to 1951, two oceanographic ships were used, the "Atlantis" and the "Karin," both of which were equipped with two hydrophones with two separate amplifying systems. At each point the recording was simultaneously conducted on two hydrophones for a more reliable separation of useful waves. Each hydrophone consisted of two Seignette's salt crystals connected into a battery and mounted together with a preamplifier to coordinate the crystals with the hydrophone cable. On the first voyage the "Atlantis" had a four-channel amplifying system. The first channel, adjusted to a frequency of 5,000 cps was set to receive the direct water wave and reflections from the bottom. The second channel had a wide-band amplifier; the third admitted frequencies below 100 cps, and the fourth -- above 20 cps. The "Karin" had reception on two-

channel amplifying systems. Each channel had a four-cascade amplifier with an amplification of 12 decibels per cascade. The filter of the first channel was tuned to frequencies of 20 to 100 cps, and of the second to freqències from 1,200 to 8,000 cps. On the second voyage the "Atlantis" worked on a high-frequency channel and on a channel admitting frequencies below 30 cps. Each hydrophone on the "Karin" was connected with a three-channel amplifying system. The first channel had an admission band of 2 to 100 cps, the second amplified frequencies from 20 to 500 cps, and the third frequencies from 1,000 to 15,000 cps. The investigators report that the recordings on the second voyage were much better.

The ships worked on the profile as follows. One of them, for example, the "Atlantis," would start drifting and run out the hydrophones, and the "Karin" moved away, setting off explosions at 5 to 15 minute intervals, and at greater distances within 30 to 60 minutes. The profile length was usually 20 to 60 miles depending on the recording conditions and the amount of available explosives. The size of the charges varied from 1 to 10 pounds of tetryl for nearby explosions and from 50 to 300 pounds for more distant explosions. Before the explosions the receiving ship would be alerted, so that the hydrophones could be lowered into the range of refracted wave action (the exact depth of submersion of the hydrophones is not indicated in the article). Reaching the end of the profile, the "Karin" stopped

and made ready for receiving, while the "Atlantis" approached and set off the explosions. In this manner, opposite hodographs of refraction waves were obtained. In the Burmada Islands region four strata were determined: unsolidified deposits with an average speed of propagation of sound waves V = 4.51 km/sec, the foundation with V = 6.63 km/sec and a second foundation with V = 8.03 km/sec. The boundary between the two foundations corresponds to the Mohorovicic surface and is located at an average depth of 10 km.

Work was conducted by the same method over a distance of 120 miles northwest from Bermuda at depths of about 5,000 m /26/. Hydrophones was lowered to a depth of about 17 m. The position of the ships was determined by the Loran phase radiogeodetic system.

In investigating the depth structure of the Brownson deep /33/ two ships were used, making recordings at the ends of a profile about 50 miles long, while a third ship was throwing 300-pound depth charges along the profile. Hydrophones were attached to buoys which kept them afloat when there was a short cable in the water. For the instant of the explosion the cable was immediately let out so that the hydrophones gradually sank at the time of recording. The maximum depth of submersion of the hydrophones was of the order of 50 m. Amplifying apparatus similar to that described above was used.

In 1955 an article was published on seismic work by the

reflected wave method on a series of profiles from Bermuda to the continental margins /45/. Two ships were used in these investigations. One recorded waves on hydrophones located close to the surface of the ocean while the other set off explosions of small charges within short intervals going away from the first ship. Explosions were set off at a depth of about 1 m. The recording was made on tape and subsequently reproduced in a laboratory. Reflections were obtained from horizons up to a depth of 1,000 to 1,100 m below the floor, which are fairly well correlated according to the profile. A comparison was made of the reflected and refracted wave method. It was found that the reflected wave method can give valuable supplementary information on the structure of the upper pile of rocks in many instances.

The article by Katz and Ewing /41/ describes the results of work conducted in 1950 and 1952 by the refracted wave method on 25 profiles west of the Bermuda Islands. Profiles 45 to 90 km long were worked on by the standard method with two ships. A recording was simultaneously made of reflected waves. The results of this work were published in an article with data of all other seismic work conducted in this area of the Atlantic Ocean.

In the United States investigations by the seismic method were begun in the Pacific Ocean in 1948. They are conducted by the Scripps Oceanographic Institution under the direction of R. Raitt. The method and apparatus used are basically similar to the above-described. In the waters off southern California

work was conducted by both methods, of reflected and refracted waves /50/. In the reflected wave method charges from 1 to 4 pounds were used, and in the refracted wave method - up to 100 pounds. Recording was made on a crystal hydrophone. The best results were obtained by the refracted wave method; the reflected wave method provided supplementary information.

Finishing the survey of work conducted in the USA, we will briefly pause to discuss the apparatus and method used in marine seismic prospecting for oil. A large volume of seismic prospecting work in the USA was conducted in the Gulf of Mexico, off the California coast and in other areas likely to yield oil /17, 40, 49/. A survey of the methods of seismic prospecting for oil, as applied until 1948, is contained in article /49/. Since similar investigations are conducted in off-shore shallow regions, seismic receivers are usually associated with the ocean floor. At first land seismographs were used in marine work; they were hermetically sealed beforehand and lowered from a ship along the profile. In subsequent years special small-bulk seismographs were designed, equipped with gimbal suspension. Apparatus usually employed contains a large number of seismographs, placed at set intervals. The wires, joined in a "braid," are lowered to the bottom, and the seismographs either float a little above the bottom, or (if they are equipped with gimbal suspension) they are directly attached to the wires. When using small-bulk seismographs with gimbal suspension, the connecting wires and the

seismographs are placed in a waterproof rubber hose which can be rolled on a drum after use. The "braid" is dragged along the bottom to move it from a station to another. In work in regions with considerably broken ground or with great depths, floating devices are used in which the wires are kept close to the surface of the sea with floats, and the seismographs are suspended at a certain depth /39, 49/. Seismic prospecting is mostly conducted by the reflected wave method. Small vessels with explosives set off explosions either in the center of the apparatus or at its ends, after which the recording vessel tows the braid to a new position.

An article /17/ published in 1950 describes a new apparatus for marine seismic prospecting by the reflected wave method, which makes it possible to do the work with a single boat moving constantly along the profile. Piezoelectric crystals are used as seismic receivers, they are contained in a plastic hose filled with oil. The whole system is neutrally buoyant in water, thus making all operations much easier. During the operation the boat proceeds along the profile at a constant rate of speed. Charges on a floating detonation mainline are lowered from the stern of the boat; explosions are set off in the center of the apparatus which has 8 to 10 channels, 100 m apart. For the instant of the explosion the motion of the hose is stopped by means of paying out the towline, as a result of which the load attached to the beginning of the hose, drops to the bottom. The use of this

apparatus and method considerably improves the efficiency of operations. Such apparatus has been in wide industrial use in the USA only for a relatively short time, approximately since 1954 /40/.

Great Britain. Marine seismic investigations in Great Britain were begun in 1938 in the East Atlantic /13, 14/. The method of Ewing was used in these first operations. The recording ship stood at anchor and lowered seismographs to the bottom. Explosions were set off from boats or motorboats also on the bottom. The distance between the explosion and receiver was determined by the time of the arrival of the water wave. As a result of this work the relief of the covering of the crystallic foundation was determined in the western part of the English Channel. The investigations were limited to relatively small depths of the ocean (150 to 200 m); penetration of greater depths was prevented by difficulties of placing apparatus and explosives on the bottom.

In 1947 the article by Hill and Willmore /34/ was published which described the results of experimental work jointly conducted during the war years by Great Britain and the USA, whose purpose was to investigate possibilities of using hydrographs to receive seismic waves. Comparisons were made of seismograph recordings which was placed on the bottom and of a hydrophone suspended in water at a depth of about 12 m. The experiments gave positive results. In the same article the authors express an

of a possible attachment of a hydrophone to a radio buoy which would translate the signal from the hydrophone to the detonation boat. Developing this idea, Hill and Swallow designed an apparatus which made it possible to conduct observations by the refracted wave method from one boat only /35, 36/. A piezocrystal hydrophone is suspended under a buoy which is floating on the surface at a depth of about 50 m. Placed within the buoy is a wide-band amplifier and transmitter which are powered by a 12-volt battery through a transformer. The amplified signal from the hydrophone is transferred to a frequency modulator of the transmitter which is working at a frequency of about 42 megahertz. When working over a profile it is usual to place three or four radiobuoys about 1 km from each other. The transmitter of the buoys are tuned to different frequencies. After placing the buoys the ship begins to throw depth charges along the profile at determined intervals, simultaneously receiving radio signals from the buoys, the signals being filtered and recorded on photographic paper by an oscillograph. The maximum distances of the profile are determined by the operational distance of the radio transmitter which operate within the range of direct vision, as well as by weather conditions. The ship usually moves away from the buoys to a distance of up to 20 miles. Explosions are set off at a depth of about 300 m; standard 200 or 300-pound depth charges are used. After working over the profile the ship returns and picks up the buoys.

This method was used in 1949 to conduct seismic investigations in the eastern part of the Atlantic Ocean at a depth of about 2,400 m /36/. The thickness of the sediment layer in this region was found to be 1,900 to 3,000 m (V = 1.5 to 2.5 km/sec), below that are crystalline rocks with a velocity of about 5.0 km/sec and a thickness of 2,700 to 3,400 m, which have basement rocks with a velocity of seismic waves of about 6.3 km/sec.

In 1948 to 1949 work was conducted by the refracted wave method in the English Channel, along a line passing south of Plymouth / 37/. Three radiobuoys were used, with hydrophones suspended at a depth of 20 m. The length of the profiles did not exceed 8 miles. The weight of the BB charges varied from 2.5 to 50 lbs. Five explosions usually sufficed for one profile. The whole operation: dropping the buoys, setting off the charges and picking up the buoys, took about 4 hours. Determinations were made of the thickness of sediment layers and the relief of the crystalline foundation.

In 1950 works by the radiobuoys method were conducted in the North Atlantic /28/ and in 1952 in the eastern part of the ocean /38/. The results of both undertakings show that in the deep-sea ocean trench, basalt rocks lie directly under the sediment layer, which has a variable thickness of an average of about 1 km. The basalt rocks extend to a depth of 9 to 13 km below sea level, where the Mohorovicic boundary has been determined. In order to obtain waves, refracted at the Mohorovicic boundary, an addi-

tional ship was used which set off explosions at distances up to 110 km from the radiobuoys. In this instance the radiobuoys were placed over a 20-kilometer profile and the recording ship was in the center of the installation.

Wide use was made of radiobuoys during the time of the round-the-world voyage of the British expedition ship "Challenger" /29/. Many seismic profiles were worked on in the Pacific, Indian, and Atlantic Oceans, and in the Mediterranean. Over most profiles in ocean depths, there are rocks with a velocity of seismic waves of 6.3 to 6.6 km/sec under the sediment layer which is about 0.5 km thick. The small length of the profiles (up to 20 miles) did not permit determination of the depth at which the Mohorovicic boundary lies.

Other countries. As far as can be judged from published works, marine seismic investigations were conducted on a relatively small scale in other foreign countries. In addition, all operations were conducted in offshore shallow areas, mostly for the purpose of prospecting for oil-bearing structures.

Thus, Mexico conducted seismic prospecting investigations in the Gulf of Mexico on an area of 1,600 km^2 along the coast of the states of Vera Cruz and Tabasco /46/.

West Germany is conducting seismic investigations by the reflected wave method in the Baltic and North Sea /1, 7, 42, 43, 44/. It is reported that good results were obtained in the Bay of Kiel and off the northwestern coast of Schleswig-Holstein /1/.

The interference level can be reduced to a considerable degree by means grouping seismographs. The apparatus used is basically similar to that used on land. Hydrophones are also used as seismic receivers /52/.

Reports were made of seismic prosepcting operations in the shallow offshore areas of Japan /31/. In order to receive refracted waves, seismographs of the electromagnetic type were used, which were placed on the bottom of the sea.

In France, marine seismic prospecting is conducted with apparatus which makes it possible to work from a single vessel in motion /12/; the apparatus and method is similar to that described in the work of Deegan /17/.

During the expedition of the Swedish investigation ship "Skagerrak," seismic investigations by the reflected wave method were conducted in the Mediterranean /30, 32/. In order to separate the reflections coming from layers located below the floor of the sea, the method of explosions at different depths was used.

Marine Seismic Investigations in the USSR

In the USSR, marine seismic operations were started in 1941 by N. I. Shapirovskiy /9/ and S. D. Shushakov in the Caspian Sea in the coastal area of the Apsheron Peninsula for the purpose of prospecting for oil-bearing structures /5/.

In 1941 to 1943 the work was of an experimental-industrial nature: apparatus and methods were developed, and at the same

time information was gathered on the geological structure of the region. By 1945, as regards technical and method aspects, Soviet marine seismic prospecting reached the corresponding level of the USA. During the 1941 to 1947 period, the method of reflected waves was used to investigate an area of about 2,500 km^2 adjacent to the Apsheron Peninsula and southeastern Kabristan, to depth of 30 m /8, 9/. Recording is made on electromagnetic seismographs with oil damping, which are kept at 1.0 to 1.5 m from the bottom of the sea, while the connecting wires in a rubber hose lie on the bottom. Up to 24 seismographs are connected to a single "braid" installation, each 20 to 30 m from the other. Explosions are usually set off at the ends of the installation from launches. After working a station the recording boat hoists anchor and tows the "braid" to a new location. Recording is made with 24 or 26-channel standard seismic stations with amplifiers, converted to marine conditions.

This apparatus and method is used by industrial crews in seismic prospecting by the reflected wave method to this day. A considerable area of the Caspian Sea has been covered by detailed and reconnaissance investigations to depths of 30 to 40 m, and sometimes deeper.

A great contribution to the development of the seismic method at sea was made by the wprkers of the scientific-research

marine expedition of the All-Union Scientific Research Institute of Petroleum and Gas (VNII) on geophysics and industrial crews of the Azerbaijani geophysical bureau of the former Ministry of the Petroleum Industry. Since 1952 these organizations have been doing experimental work on the use in the Caspian Sea the correlative method of refracted waves (KMPV).

The penetration of seismic prospecting to greater depths of the sea, under the existing method and technique of operation, is being hampered, since it is connected with difficulties of placing a seismographic "braid" on the bottom of the sea. The first experimental work at depths between 150 and 200 m was conducted in 1952 by a seismic crew of the marine expedition of VNII on geophysics. It was found in these experiments that the usual seismographic "braid" was unsuitable for deep-sea work. It is very difficult to raise the heavy "braid" on board ship from the bottom of the sea. Great hydrostatic pressure warps the housing of seismographs and equipment gets out of order; leaks occur in connecting wires as a result of water seepage; floats get water-logged and there is a loss of buoyancy. In 1953, experiments conducted at great depths were for the time being continued with the old equipment.

By that time great forward strides were made in the design of a new seismographic "braid" for marine seismic prospecting, conducted by VNII on geophysics together with the chair of

geophysics of the Department of Geology of Moscow State University (G. I. Rudakovskiy, S. M. Zverev, Yu. P. Neprochnov). A small-bulk seismic receiver was designed with a Seignette's salt crystal, and it was proved that it could be used in marine seismic prospecting /2/. The piezoseismic receivers and wires were placed in a plastic hose which was filled with oil, so that the whole installation would be in a state of suspension in water. In 1954, using such a piezoseismographic "braid" with 12 recording channels, experimental work was done in many regions of the Caspian Sea. For each channel of the piezo braid there was a group of 10 seismic receivers; the distance between the centers of neighboring groups was 50 m. That same year a piezoseismographic "braid" was tried at great depths of the sea (region of the Ignatiy rocks). Here, for the first time in the USSR a recording was made of reflected waves during the motion of a ship and "briad" and the prospects of this method were determined.

In the summer of 1955 work with a piezoseismographic "braid" were conducted on a wider scale off the Turkmenian coast of the Caspian Sea. A method was developed of recording the reflected waves while the ship was moving, and thus, within a short time, detailed investigation was made of the deep structure of the underwater continuation of the Cheleken Peninsula. Experimental work was conducted at depths of the sea between 70 and 80 m

in the region of the Livanov bank. While working over the profile the ship was moving at a steady speed of about 5 km/h, towing behind the stern the piezo braid at a depth of about 10 m (this depth, as special experiments showed, is the best for a pressure receiver in recording reflected waves in the region under investigation). Explosions of 5-kilogram charges were set off from a launch which was also towed by the ship. An experimental profile 10 km long was wooked on over the Livanov bank by the method of continuous profiling with reflected waves. It was found on the basis of the seismic cross section obtained that there was an anticlinal fold in this region.

In 1956, work was organized according to the plan of the preparations for the International Geophysical Year of deep seismic sounding of the earth's crust in the Caspian Sea. The investigations were jointly conducted by a number of organizations (Institute of Terrestrial Physics Acad Sci USSR, VNII on geophysics, the Azerbaijani scientific research institute on petroleum extraction, and the Institute of Oceanology Acad Sci USSR). A choise was made of the apparatus and a method was developed of regional seismic work at sea. In the course of this work in the Caspian Sea a total of 12 profiles were worked on, extending from 100 to 200 km. Usually recording was simultaneously made by two or three land stations and by two or three ships. The land stations were located on the west and

east coast, and on Zhiloy island. The ships recorded seismic waves by means of hydrophones, connecting the piezocrystal and preamplifier. The outlet of the preamplifier was transmitted to several amplifiers which operated at different frequencies. The wave refraction was usually well recorded on frequencies of 6 to 12 cps, and direct water waves -- on the high-frequency channel. Recording was made on photographic paper with oscillographs. In working over profiles the recording ships usually rested at anchor and hydrophones were lowered to the bottom of the sea. The detonating ship threw 135-kilogram depth charges at intervals of 5 to 10 km along the profile. The positions of the ships were determined by radiogeodetic apparatus.

Seismic investigations in the Pacific Ocean were begun in 1954, by the Institute of Oceanology Acad Sci USSR /4/. Work was conducted on the oceanographic ship "Vityaz'" by the method of reflected and refracted waves. For regarding of waves apparatus was used containing hydrophones, amplifiers, octave filters and a film oscillograph MPO-2. The octave filters made it possible to pick the required band frequency. Recording was usually conducted on two hydrophones at the same time, one of which was lowered to a depth of 20 to 50 m, and the other to 70 to 150 m. During work by the reflected wave method explosions were set off also from the "Vityaz'." Charges of the order of several kilograms

were used which were electrically detonated. Recordings were made of direct water waves reflected from the ocean bottom, as well as those reflected from two or three lower-lying horizons. In order to separate the below-floor reflections, a frequency criterion was used. Reflections were obtained from horizons at depths up to 900 m below the ocean floor. In work by the refracted wave method, an auxiliary detonation boat was used /3/.

In 1956, work by the reflected wave method was conducted during the Antarctic Expedition of the Academy of Sciences USSR by the diesel-electric ship "Ob'."

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QUALITATIVE AND QUANTITATIVE CHARACTERISTICS OF THE DEEP-SEA BOTTOM FAUNA OF THE OCEAN

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Introduction

The data concerning the qualitative and quantitative distribution of the bottom fauna of the ocean bed, which comprise about 70 per cent of the entire surface of the earth crust, represents an extremely important part of our general concepts about the distribution of life in the biosphere. Both the qualitative composition and the quantitative distribution of the bottom fauna are in this respect equally interesting. Some of the most characteristic properties of the composition and distribution of the bottom fauna at greatest ocean depths were made apparent only within the recent years, in connection with the development of deep-sea explorations. It should be pointed out that opinions about lifelessness of ocean depths exceeding 6000--7000 m were expressed only several years ago. The uniqueness of the fauna at great depths is first of all examplified by its systematic composition, as well as by the vertical and geographic distribution. Popular quite recently was the opinion about the great

uniformity of fauna of the abyssal zone both in various oceans and in their individual parts. At the present time there are reasons to assume that, along with a substantial qualitative impoverishment of the ocean fauna as a whole, an increase in the diversity of the deep-sea fauna proper takes place as the depth increases. The data existing today indicate that the population of various deep-sea depressions is characterized by a clearly expressed taxonomic individualization, and thus by a considerable endemism. As far as the quantitative characteristics of the bottom fauna is concerned, one may, on the basic of contemporary data, speak in terms of a decrease sometimes of thousands and tens of thousands of times in the quantitative abundance (biomass) of the ocean fauna in the remote deep-sea regions of the ocean, as compared with the littoral shallows. Besides, the degree of this decrease varies strongly in different regions.

One may assume that the study of the fauna of the depths of the World Ocean bed began with the famous "Challenger" expedition in 1872—1876, under the leadership of Wyville-Thomson. During this expedition 30 successful sweepings at depths of 4000—5000 m and 12 sweepings at depths exceeding 5000 m were carried out in various regions of the World Ocean, up to a maximum depths of 5770 m in the central part of the Atlantic Ocean, near the Tropic of Cancer /79/. The special deep-sea expedition on the "Valdivia" in 1898—1899 and a number of other expeditions in the last quarter of the nineteenth century succeeded in making collections of the bottom fauna only at depths of less than 6000 m. Only the expedition on the American vessel "Alba-

tross" trawled at a depth of 7,632 m in the Tonga Trench in 1899 the haul, however, brought up only fragments of siliceous sponge, similar to the sponge obtained by the "Challenger" expedition at a depth of 1,000 m in the western part of the Pacific Ocean. It remains unexplained whether these are fragments of a sponge that actually lives at such a great depth or whether they are the skeletal remains which found its way here from lesser depths /70/.

In our home waters, deep-sea fauna was investigated in the seas of the Far East by a number of expeditions directed by K. M. Deryugin in 1932 and 1933 /17 to 19, 36, 37/, in the Polar basin by the expedition on the icebreaker "Sadko" in 1935 through 1938 /16/, and near southeast Kamchatka by A. P. Andriyashev in 1946 /2/, but all collections of these expeditions were made at depths less than 4,500 m.

Not counting the haul made by the ship "Albatross," up to 1948 the most successful trawl, which brought up a catch of various animals from the bottom, was that made early in the 20th century by the Prince Albert of Monaco expedition, at a depth of 6,055 m in the eastern part of the central Atlantic /44/. The work of these, and similar expeditions of the post-Challenger period, including the series of deep-sea expeditions of the last decade, did not yield essential new data which would substantially broaden our ideas of the distribution of life at depths greater than the mean ocean floor depth. Only in the last decade, due to the work of a number of deep-sea expeditions, extremely great

advances were made in studying the deep-sea fauna, particularly the fauna of the maximum ocean depths.

The data on the routes of the three round-the-world expeditions of the last decade ("Albatross II," "Challenger II,", and "Galatea") and the general characteristics of explorations conducted by them, as well as the work of the expedition vessel "Vityaz'" of the Institute of Oceanography of the Academy of Sciences of the U.S.S.R., are given in the introductory article of this collection /25/. As far as special explorations of the bottom fauna by these expeditions are concerned, the "Challenger II" did not conduct any work in this field. Collections of the bottom fauna made by the Swedish deep-sea expedition on the "Albatross II" (1947--1948) were limited to regions of the Atlantic Ocean between the equator and 44° N. Lat. This expedition made 12 sweepings, including 11 at ocean depths from 4000 to 6000 m, and one (on August 18th, 1948) at a depth of 7695--7900 m in the Puerto Rican Trench. The haul obtained from this depth contained only a small amount of the bottom fauna in a very poor state of preservation /70/. Detected in it were several hollow tubes of Polychaeta of the Terebellidae family, fragments of the Macellicephala sp. of Polychaeta, a large good deal of Amphipoda aff. Paracallisoma sp., and four specimens of three other species (Metandania islandica Stephensen, Eusirus bathybius Schellenberg, and Synopioides secunda Stebbing), one Isopod belonging to a new genus and species — Bathyopsurus nybelini Nordenstam, and fragments of about twenty specimens of Holothurioidea of the genus Peniagone or Scotonassa /51, 63, 69, 72/. The

results of processing of the deep-sea fauna collected by the Swedish expedition were published in a number of articles and in two special issues of Reports of this expedition (Reports of the Swedish Deep-sea Expedition 1947—1948, vol. II, fasc. 1, 1951, and fasc. 2, 1955). Each of these articles contains also a summary of bibliographical data on all occurrences of representatives of the corresponding systematic group at depths exceeding 3000 m.

Table 1

Composition of the bottom fauna obtained by the "Vityaz'" at a depth of 8100 m in 1949

Systematic group	Species	Number of specimens
Spongia	G. sp.	1
Actiniaria	Galatheanthemidae	6
	G. sp.	1
Polychaeta	*Amphicteis mederi* Annenkova	About 20
	Vitiazia degieli Uschakov	1
	Macellicephala zenkevitchi Uschakov	1
	Macellicephaloides grandicirra Uschakov	1
	Lumbriconereis sp.	4
	Potamilla sp.	3
Echiuroidea	*Jakobia birsteini* Zenkevich	1
Bivalvia	Propeamussium sp.	1
Cephalopoda	Octopoda	1
Crustacea Isopoda	*Storthyngura herculea* Birst.	7
Amphipoda	G. sp.	Several
Holothurioidea	*Elpidia glacialis* Théel	About 20
	Pseudostichopus sp.	3
Pogonophora	*Heptabrachia abyssicola* Ivanov	1
	Siboglinum caulleryi Ivanov	Several
	Siboglinum sp.	
Enteropneusta	G. sp.	1?

The sweeping in the Puerto Rican Trench was record-breaking

with respect to depth up to October 10th, 1949, when the "Vityaz'" carried out a sweeping at a depth of 8100 m, which yielded a large and varied catch, in the north-western part of the Pacific Ocean, in the Kurile-Kamchatka Trench /8. 21. 29. 35. 39. 40/. This haul contained more than 140 specimens of 20 species of bottom invertebrates belonging to 10 various classes (Table 1).

Great merit in the field of studies of the deepsea fauna belongs to the Danish expedition on the "Galatea" in 1950—1952. In the course of the round-the-world voyage of the "Galatea," in addition to numerous collections of fauna from depths of the World Ocean, five deep-sea trenches were explored in the Indian and in the Pacific Ocean (Table 4). In these trenches, at depths of more than 6000 m, 17 sweepings were made and 5 dredging samples taken. The three most abyssal sweeping catches were obtained from the Philippines Trench from depths of 9790, 10150, and 10160—10210 m, and the most abyssal dredging sample was taken in the same trench, from a depth of 10120 m. /76/. The first catch from a depth of more than 1000 m was obtained on July 22nd, 1951 /46/. The following animals were collected by the "Galatea" from the three greatest depths /46, 48, 56, 59, 76, 81/:

Actinaria *Galatheanthemum hadale* Carlgren	40	specimens
Polychaeta *Macellicephala hadalis* Kirkegaard	2	fragments
Echinoidea G. sp.	5	specimens
Bivalvia G. sp.	5	"
Crustacea Amphipoda G. sp.	1	"
Isopoda *Macrostylus galatheae* Wolff	3	"
Holothurioidea *Scotoplanes galatheae* Hansen	1	"
Myriotrochus bruuni Hansen	100	"

The dredging sample from the depth of 10120 revealed only one specimen of the Holothurioidea Myriotrochus bruuni Hansen.

Thus, the research tools for collection of the bottom fauna reached in 1951 both in terms of quality and of number the greatest depths of the World Ocean, and the existence of a diversified life at any depths of the ocean was proven. Materials collected by the [illegible] are at the present time partially already processed by specialists, and their publication was begun in the Galathea Reports series. The second volume of this edition, containing articles devoted to various groups of bottom invertebrates (Coelenterata, Nematodes, Polychaeta, Isopoda, Tanaidacea, Pantopoda, Echinodermata, Pogonophora), was published in 1956. Cited in most of these articles are the results of processing only of those representatives of the corresponding groups, which were collected at depths exceeding 6000 m.

The work of the "Vityaz'" on the study of deep-sea fauna, which began in 1949, were continued in 1950--1955 and encompassed our Far-Eastern seas and the adjoining north-western part of the Pacific Ocean (Table 2). During four voyages of the "Vityaz'" in 1953--1955, numerous sweepings in depths of the ocean bed were carried out, and six deep-sea trenches were explored, from the Aleutian to the Mariana and the Ryu-Kyu (Table 4). During this period the "Vityaz'" conducted 21 sweepings and took 7 dredging samples at depths of more than 6000 m. The three most abyssal hauls were obtained while sweeping in the Kurilo-Kamchatskaya Trench at depths of 9000--9050 m and 9700--9950 m and in the Idzu-Bonin Trench at depths of 9715--9735 m. The most abyssal dredging sample was taken in the Aleutian Trench from a depth of 7286 m. Table 2 summarizes the data concerning the number of deep-sea

sweeping and dredging samples taken by the "Vityaz'".

Table 2

The number of sweeping and dredging samples obtained by the "Vityaz'" from depths exceeding 1000 m in 1949—1955

Depth in m	Sea of Japan		Sea of Okhotsk		Bering Sea		Pacific Ocean		Total	
	sw	dr	sw	dr	sw	dr	sw	dr	sw	dr
1000—3000	5	12	13	55	7	10	10	17	35	94
3000—6000	1	3	4	12	11	18	23	38	30	71
More than 6000	—	—	—	—	—	—	21	7	21	7

At the present time, among all the deep-sea trenches of the ocean, the Kurile-Kamchatka Trench, where 17 sweepings at depths exceeding 1000 m and 9 at depths from 6000 to 10000 m were made, has been explored in greatest detail. Preliminary results of exploration of the Kurile-Kamchatka Trench were published in articles of L. A. Zenkevich, Ya. A. Birshteyn, and G. M. Belyayev /26,27/, and results of detailed processing of the material by separate systematic groups were given in a number of articles by various authors /4, 8, 11, 24, 30, 35, 40, 41, 42/.

Finally, one should mention the work of the Consolidated Antarctic Expedition of the Academy of Sciences of the U.S.S.R., which was begun in 1955 on the vessel "Ob'." The "Ob'" made collections of the deep-sea fauna in 1956 in the Antarctic waters and in the Indian Ocean and were carried on in 1957 and 1958 in the same regions and in the southern part of the Pacific Ocean.

Table 3

Number of sweeping catches obtained by various expeditions

from depths of more than 6000 m

Expedition	Depth in m: 6000–7000	7000–8000	8000–9000	9000–10000	10000–10610	Всего
American on the "Albatross," 1899	—	1	—	—	—	1
Prince Albert of Monaco, 1901	1	—	—	—	—	1
Swedish on the "Albatross II", 1947--1948	—	1	—	—	—	1
Soviet on the "Vityaz'," 1949	—	—	1	—	—	1
Danish on the "Galathea," 1950--1952	7	4	3	1	2	17
Soviet on the "Vityaz'," 1953--1955	8	5	4	3	—	20
Total	16	11	8	4	2	41

Tables 3 and 4 summarize the data on the number of sweeping hauls conducted by various expeditions at depths exceeding 6000 m. As can be seen from these tables, up to the present time material has been already accumulated on the fauna of greatest ocean depths from 12 various deep-sea trenches. However, inasmuch as the overwhelming part of these collections was carried out only within the recent years ("Galathea," "Vityaz'"), the accumulated material is basically still in the processing stage. The completion of this processing will undoubtedly yield a rich and interesting material, capable of serving as a basis for broad generalizations in the problems of vertical and geographic distribution of the deep-sea fauna, of its genesis, etc.

Table 4

Regional distribution of sweeping catches made by various expeditions at depths exceeding 6000 m (up to 1957)

Region	Number of catches	Depth in m	Expedition
Atlantic Ocean			
Puerto-Rican Trench	1	7625–7900	Swedish "Albatross II"
Western part of Central Atlantic	1	6035	Prince Albert of Monaco
Indian Ocean			
Java Trench	2	6930–7160	"Galathea"
Pacific Ocean			
Aleutian Trench	2	6410–7245	"Vityaz'"
Kurile-Kamchatka Trench	9	6860–9850	"
North-western part of the Pacific Ocean	3	6000–6280	"
Japan Trench	2	6100–7280	"
Idzu-Bonin Trench	3	7305–9735	"
Mariana Trench	1	7585–7615	"
Ryu-Kyu Trench	1	6810	"
Philippines Trench	3	9790–10210	"Galathea"
Banda Sea Trench	4	6490–7280	"
Bougainville Trough	2	8810–8940	"
Kermadek Trench	6	6140–8300	"
Tonga Trench	1	7632	American "Albatross"

Methods of Collection of the Deep-sea Fauna

The Agassiz trawl, which was first employed by the expedition on the vessel "Blake" in 1877 /68/ and which entered our literature under the more common name of Sigsbee trawl and which is sometimes also called the sled trawl, remains up to this time the principal tool for collection of deep-sea bottom fauna. In recent years this model

is being used with various major or minor modifications. A very important device was introduced into practice in the 'thirties by G. P. orbunov /16/. This device consists in flexibly mounting two rods, equal in length to the tied trawl bag, to the sides of the trawl frame.

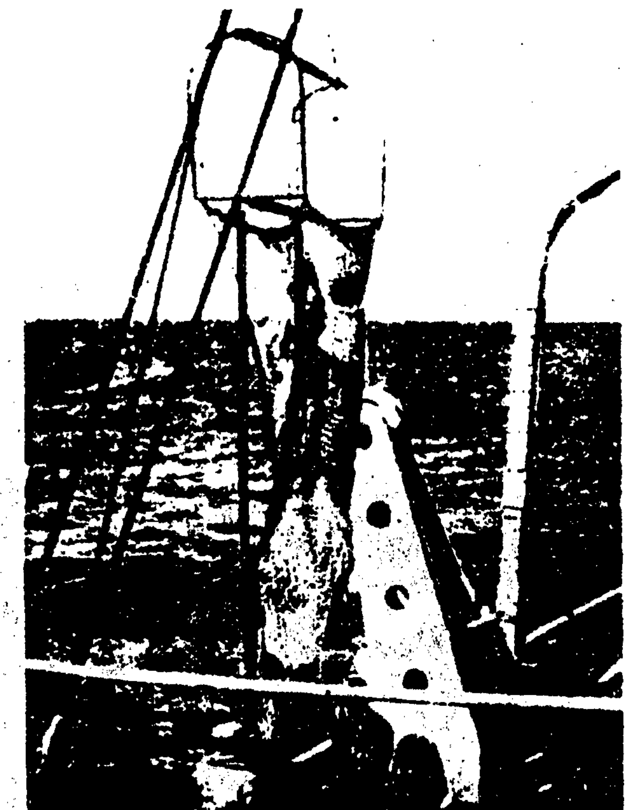

Fig. 1. Sigsbee-Gorbunov trawl on the "Vityaz'." Photo by V. Nartsissov.

The trawl bag is fastened by outhauls to the rods, which prevents it from being wrapped around the frame when the trawl is lowered. Exactly this model (the Sigsbee-Gorbunov trawl) found a predominant employment during work on the "Vityaz'," where its frame was 2.5 m wide and its weight about 200 kg (Fig. 1). As it is known, the trawl

offers the possibility of making only a qualitative account of the fauna. However, due to the meager representativeness of dredges as quantitative tools of hauling at great depths, due to the rarity of settlements of the deep-sea fauna (in any case of the more or less large animals), making a quantitative estimate on the basis of trawling hauls was of a substantial interest. A member of the Institute of Oceanography, Ye. I. Kudinov, constructed for this purpose an instrument -- trawlograph -- which recorded the length of the path covered by the trawl at the bottom. The data on utilization of the trawlograph during deep-sea sweepings of the "Vityaz'" are given in the article of L. A. Zenkevich, Ya. A. Birshteyn, and G. M. Belyayov /27/.

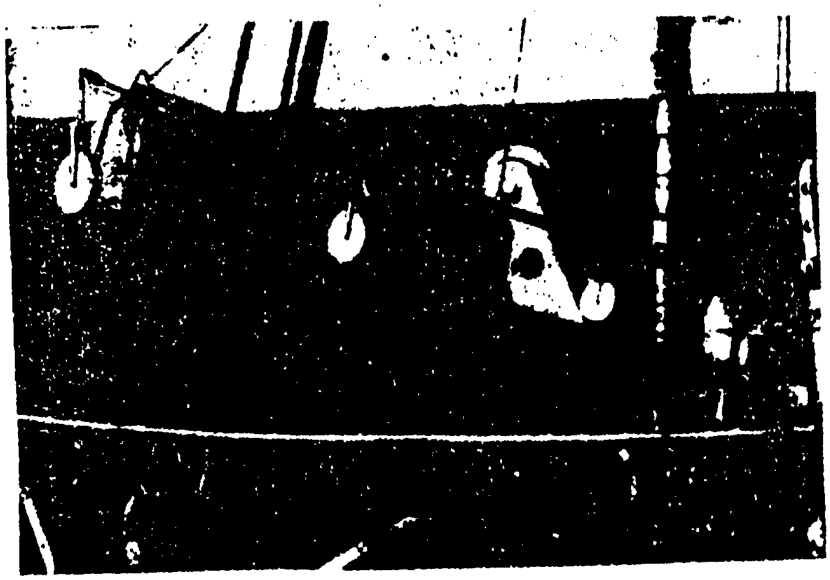

Fig. 2. Double trawl used on the "Vityaz'," constructed according to the trawl type used first on the "Galathea." Photo by V. Nartsissov.

The most significant modification of the Sigsbee trawl is the model employed during the work of the "Galathea" expedition, along

with the regular type /44/. The frame of the modified type is 6 m wide and 75 cm high, and weighs only 40 kg. The trawl is provided with two bags, each 3 m wide, which are placed side by side. A somewhat heavier model of this type was successfully employed in 1955, as well as on the "Vityaz'" (Fig. 2). The Swedish expedition on the "Albatross II" in 1947--1948 employed for deep-sea sweepings a ten-meter otter trawl, which made several successful sweepings at depths of up to 7900 m. However, judging by the description of hauls obtained by this trawl /70/, it catches well fish, but is of little effect-

Fig. 3. Ring trawl being attached to the trawl warp from the storm trap-ladder lowered from the vessel's stern, during sweeping conducted by the "Vityaz'" from the anchor winch at a depth of 9700 m. Photo by G. Belyayev.

ivness as far as collection of deep-sea bottom invertebrates is concerned.

For deep-sea sweeping on the "Vityaz'," perlon ring trawls with a 160 cm diameter were fastened to the trawl warp at various intervals from the trawl, in order to make horizontal hauls in the water column at various horizons. These ring trawls yielded usually rich catches of deep-sea fish, crustaceans, and of other bathypelagic animals.

Fig. 4. Grab of the "Ocean 50" type on the "Vityaz'" before being lowered. Photo by V. Kartsissov.

Employed for quantitative collections of the bottom fauna by all contemporary expeditions are grabs representing various modifications and improvements of the Petersen grab, which has been in use for almost half a century. A grab of this type, with an opening area of

0.2 m^2, was used for deep-sea work on the "Galathea." Up to 1950 the "Vityaz'" employed the ordinary Petersen grab with an opening area of 0.25 and 0.4 m^2, and from 1950 on, the "Ocean 50" (0.25 m^2) type grab, designed by members of the Institute of Oceanology A. P. Lisitsyn and G. B. Udintsev /51/. This model is distinguished by a device which prevents the grab from closing in the water column while being lowered (Fig. 4). A similar device exists on a somewhat modified Petersen grab (Campbell grab), which is used by the American exploration ship "Valero IV" of the University of Southern California. In addition, this ship uses also a peculiar four-door Hayward grab (Fig. 5), which bears, due to its unique shape, the name "orange peel" /57/.

Fig. 5. Four-door Hayward grab on the "Valero IV" /57/.

As Ekman pointed out only recently /50/, the method of collecting the smallest bottom animals is up to this time unsatisfactory. In connection with this one should mention the method of washing the deep-sea dredging samples in a silken gauze bag with mesh diameter of 0.5 mm (No. 140), which is placed in a tank with circulating sea water. If

a significant amount of unwashed soil remains at the bottom of the bag after washing, an elutriation of animals contained in it is made. Although this washing method consumes often substantially more time than the usual methods of washing the samples on metal washing screens (especially when washing clay soils), it has a material advantage as compared with the latter. Owing to the small mesh diameter of the silken gauze, the preservation in the sample even of the smallest animals, less than 1 mm large (Nematodes, Harpacticoida, etc.), is guaranteed. Besides, inasmuch as the soil being washed is not subjected to the direct effect of the water jet from the washing hose, even the most fragile and delicate organisms are preserved in the sample undamaged. The utilization of this method permitted, during the work on the "Vityaz'," to obtain rich collections of various small deep-sea bottom organisms which were up to this time studied only to a very insufficient extent.

General Characteristics of Deep-sea Biocoenoses

The first attempt to give a qualitatively communal characteristic of the bottom population of the open regions of the ocean, including the deep-sea regions, was made by Petersen /71/ in the well-known scheme, published by him in 1915. In this scheme Petersen gives a number of bottom communities of the north-eastern part of the Atlantic, up to Eastern Greenland, Spitzbergen waters, the Barents, White, and Baltic Seas in the north and the east, and up to 48° S. Lat. to the south. For deep-sea regions (exceeding 1000 m) of the Greenland and Norwegian Seas he indicates a community with a characteristic form of

Pecten frigidus. The regions with depths from 1000 to 2000 m south of Iceland and west of Great Britain and Ireland are referred by Petersen to the community of Pecten vitreus, Abra longicallis "and of various other characteristic, or at least important accompanying, species" (page 5). As far as the community set off by Petersen for the more southern regions of the Atlantic with depths exceeding 2000 m, is concerned, the author notes that it is for him impossible to point out any widely distributed characteristic species. It should be noted that Petersen's scheme had only a stricly orientating importance and was to a significant degree even hypothetical.

Twenty years since, on the basis of results of concrete quantitative investigations of the bottom fauna, Spärck thought it possible, due to extreme poverty of data, to indicate only two deep-sea communities in the Atlantic: the community of Foraminifera in the waters of Scotland and of Eastern Greenland at depths up to 700 m, and the community of Pecten vitreus at depths exceeding 200 m in a very limited region of the Skagerrak and of the Oslo Fjord./73/. In 1956, comparing the above mentioned Petersen's scheme with data of biocoenosis explorations accumulated in the course of two decades, Spärck /74/ made an attempt to deliniate the bottom communites from low depths up to the upper horizons of the abyss and to give their classification. Into his treatise on these communities Spärck introduced, on one hand, the zoogeographic principle, and on the other, the principle of their demarcation according to depth and partially according to their adaptation to various soils. Thus, for example, Spärck distinguisehs a

boreal shallow-water community (Danish waters and the Baltic), an arctic community of intermediate depths and of soft soils (in the Spitzbergen region and near Eastern Greenland), etc. It should be noted that all communities defined by Spärck are fixed to coastal and relatively shallow regions of the Atlantic. As far as the region of distribution of great depths is concerned, Spärck points out only a single deep-sea community near the south-eastern coast of Greenland and notes that data for any further synthesis are absent. Up to this time we have no other generalizing studies on the communal distribution of the bottom fauna in the Atlantic Ocean.

With respect to other regions of the World Ocean, up to a recent time we had no data whatsoever at our disposal which would characterize the communal distribution of the deep-sea fauna. In 1949 the explorations of the "Vityaz'" were begun, which encompassed, in the period from 1949 to 1955, the deeps of the Seas of Japan and of Okhotsk and of the Bering Sea and of the adjoining regions of the Pacific Ocean at a total area of more than 5 million km^2. The results of the preliminary generalization of these data, illustrated by a scheme of qualitative distribution of the bottom fauna in the Far-Eastern seas and in the north- western part of the Pacific Ocean (Fig. 6), are given in article by L. A. Zenkovich and Z. A. Filatova /28/. According to these authors, the qualitative distribution of the bottom fauna is determined basically by the extent of isolation of the sea basin from the open ocean, by the degree of remoteness of a given region from shores, and by the depth of the habitat. On the basis of comparison

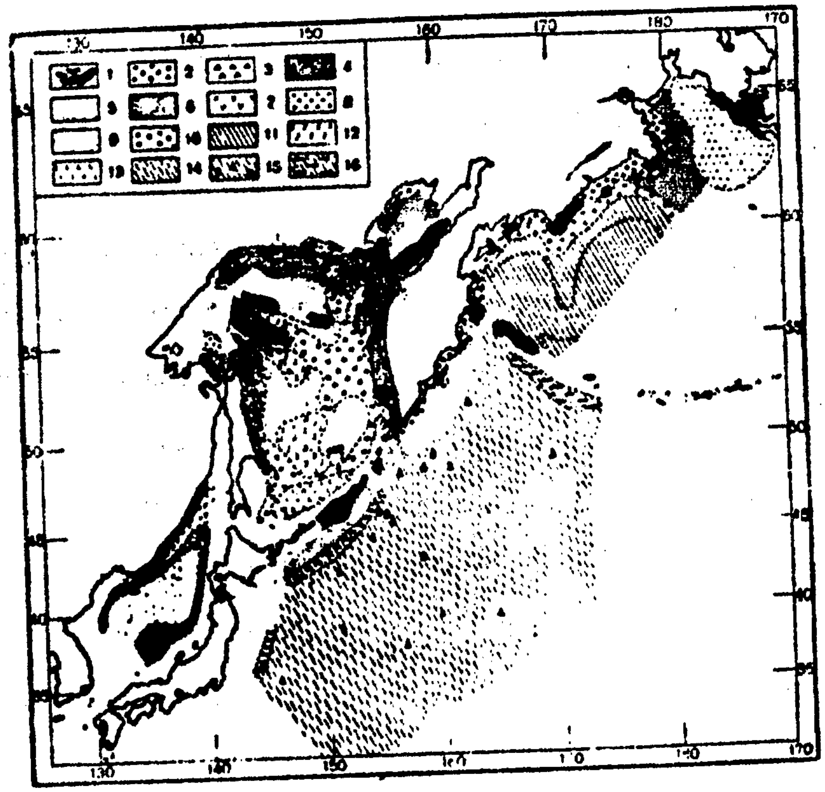

Fig. 6. Scheme of qualitative distribution of the bottom fauna in the Far-Eastern seas and in the north-western part of the Pacific Ocean /28/.

1) Fauna of overgrowing (sponges, hygroids, bryozoans, etc); 2) Echinarachnius parma; 3) Cardium ciliatum, etc.; 4) Macoma calcarea; 5) Ophiura sarsi; 6) Small bivalves; 7) Heliometra glacialis — Ophiura sarsi; 8) Pogonophora Siboglinum; 9) Miscellaneous Polychaeta; 10) Irregular sea urchin Brisaster; 11) Hyaline sponges (Triaxonida), Holothurioidea, Pogonophora, etc.; 12) Potamilla symbiotica; 13) Lamellisabella zachsi, etc.; 14) Elpidiidae, Psychropotidae, Porcellanasteridae, etc, 15) Spinula (Malletiidae, Bivalvia); 16) Elpidia, Macellicephala, Thalassema, etc.

of fauna in the same vertical zones in various parts of the whole vast explored region the authors arrive at the conclusion that differences exist between the fauna of the sublittoral, the bathyal, and the abyss of the marginal Far-Eastern seas and the fauna of the corresponding vertical zones in the adjoining regions of the Pacific Ocean.

L. A. Zenkevich and Z. A. Filatova show for the sublittoral of the Far-Eastern seas a series of various communities whose composition and distribution is determined by their fixation to the various levels of the sublittoral (the upper and the lower), and, within each level, primarily by the nature of the soil, as well as by the geographic location of the area, the near-bottom temperature, and by the currents. "In the bathyal of the Sea of Okhotsk and of the Bering Sea, as well as near the oceanic coast of Kamchatka, a very characteristic infaunal biocoenosis has everywhere a considerable development, where the irregular sea urchin Brisaster is the predominant species, along with typically soil-consuming and detritus-consuming species accompanying it -- Ctenodiscus crispatus, Trochostoma (in the Sea of Okhotsk), or Joldia beringiana, Holothurioidea (in the Bering Sea)." With respect to the abyssal zone, in the Bering Sea it is "...characterized by the deep-sea community, which contains various hyaline sponges, Holothurioidea, Actinaria, large Bathysiphon, and, of Echiuridea, the Tatianellia gracilis." For the abyss of the Sea of Okhotsk the authors indicate the community Potamilla Symbiotica for its less deep parts, and the community of Pogonophora Lamellisabella zachsi, Foraminifera Bathysiphon and Echiuridea Tatianellia grandis for the greatest

depths of the southern basin of the Sea Okhotsk. Finally, two communities are named for the open areas of the north-western part of the Pacific Ocean. Typical of the northern slopes of the Kurilo-Kamchatskaya Trench is the community where various species of Polychaeta predominate. "The bed of the Pacific Ocean is occupied by a fairly uniform community of typical deep-sea oceanic species, most characteristic among which are, of Holothuricoidea, the Elpidiidae and Psychoropotidae, of Asteroidea, the Porcellanasteridae and Brisingidae, of sea urchins, the Pourtalesiidae and Echinothuriidae, several species of Actiniaria, madrepore corals, Bathycrinus lily, and of Polychaeta, the representatives of the families Maldanidae and Ampharetidae. A very characteristic member of this community is the universally encountered bivalve of the family Malletiidae, the Spinula oceanica." (page 159).

M. N. Sokolova offers a much more refined system of the deep-sea bottom communities in the abyssal parts of the Sea of Okhotsk and in the Bering Sea in the area of the Kurile-Kamchatka Trench /33, 34/. On the basis of quantitative relationships of various representatives of the bottom fauna in sweeping hauls from depths exceeding 1000 m, Sokolova distinguishes 11 basic and 6 transitional communities and gives their ecological characteristics. Four of these communities are encountered at depths between 1000 and 3000 m, one at depths of 1000 to 4000 m, seven are fixated at depths from 3000 to 5140 m, and four are finally characteristic only of maximum ocean depths of more than 6000 m. On the ground of analysis of feeding of the prevailing species in each community, the characteristics of alimentary groupings

of the bottom invertebrates in each community and of nutritive interrelationships within the community are given. As Sokolova points out, the greater part of deep-sea bottom invertebrates belongs to sestonophags and to soil-consumers. Therefore, according to the opinion of this author, the peculiarities of distribution of clastic deposits and of the material suspended in the near-bottom layers of water, stipulated by the velocity and direction of abyssal near-bottom currents which are in turn dependent on the nature of the relief of the sea floor, must have the decisive importance for the distribution of the deep-sea benthos. Ecologically monotypic deep-sea bottom communities have been identified by Sokolova at various depths of the explored region, at similar conditions of deposit accumulation and of distribution of near-bottom suspended material.

Regularities of the Change of Composition of the Bottom Fauna with Respect to Depth

As the depth of the habitat increases, a sharp decline in the abundance of species in the bottom fauna takes place. This regularity was observed even by Murray as a result of generalization of data concerning the number of species in sweeping catches made by the "Challenger" expedition (Table 5).

Complete lists of species prevalent at depths exceeding 3000 m are given in the Reports of the Swedish deep-sea expedition of 1947—1948 for a number of systematic groups. Information on the distribution of botton invertebrates at great depths, reported at the Fourteenth International Zoological Congress (published in the col-

lection "On the distribution and origin of the deep-sea bottom fauna." 1954. Union Intern. Sci. Biol., Ser. B., No. 16) and in the second volume of the "Galathea Report," as well as data on processing of deep-sea collections of the "Vityaz'," partially published and partially reported to us by a number of specialists engaged in processing these collections, may serve as a supplement to the above data. By

Table 5

Average number of species of bottom animals at various depths in sweeping catches of the "Challenger" (according to Murray, 1895)

Depth in m	Number of stations	Average number of species per station
Less than 180	70	60,7
180--900	40	47,1
900--1800	23	26,8
1800--2700	25	19,7
2700--3600	32	12,3
3600--4500	32	7,7
More than 4500	25	6,1

summarizing all this information[1] it was possible to obtain better differentiated indicators of the change in the abundance of species of the bottom fauna with respect to the increase of depth. Such indicators for 16 various groups of bottom animals are given in absolute values in Table 6[2] and in percentile expressions in Table 7. As can be

1 With respect to crustacean Amphipoda, the recently published data on finding five new species in the region of the Puerto Rico Trench were also accounted for.

2 It should be borne in mind that collections both of "Galathea" and of "Vityaz'" have been up to this time only partially pro-

Change in the Number of Species of Various Bottom Invertebrates with Respect to Increase in the Depth (Absolute Values)

Groups of bottom animals and approximate total number of species

Habitation by depths in m	Hydroidea	Actiniaria	Polychaeta	Echiuroidea	Sipunculoidea	Bryozoa	Cirripedia	Amphipoda	Isopoda	Pantopoda	Asteroidea	Ophiuroidea	Echinoidea	Holothurioidea	Crinoidea	Pogonophora	Total of the 16 groups named
	2700	1120	[illegible]	75	250	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1500	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] 28100
deeper than 3000	14	44	176	12	21	47	34	41	96	26	132	100	47	143	19	30	992
4000	12	30	122	11	14	14	13	28	49	15	58	44	15	100	12	16	553
5000	8	18	64	9	5	4	3	17	39	4	21	10	6	41	4	13	266
6000	2	10	33	7	3	0	1	14	29	2	6	5	2	19	2	11	146
7000	2	8	22	6	1	—	0	6	12	0	2	1	1	15	2	10	88
8000	1	6	14	3	1	—	—	4	5	—	0	0	0	9	2	10	55
9000	0	3	3	2	0	—	—	1	1	—	—	—	—	3	1	7	21
10000	—	2	1	1	—	—	—	0	0	—	—		—	1	0	0	5

Table 7

Change of the relative abundence of species in various groups of bottom invertebrates with respect to increase in the depth (in per cent of the total number of species of the given group)

Groups of bottom animals

Habitation by depths in m	Hydroidea	Actiniaria	Polychaeta	Echiuroidea	Sipunculoidea	Bryozoa	Cirripedia	Amphipoda
Deeper than 3000	0,5	3,9	3,9	16,0	7,5	1,2	5,2	0,6
4000	0,4	2,7	2,7	14,7	5,0	0,4	2,0	0,4
5000	0,3	1,6	1,4	12,0	1,8	0,1	0,4	0,3
6000	0,07	0,9	0,7	9,3	1,0	0	0,2	0,2
7000	0,07	0,7	0,5	8,0	0,4	—	0	0,1
8000	0,04	0,5	0,3	4,0	0,4	—	—	0,06
9000	0	0,3	0,1	2,7	0	—	—	0,01
10000	—	0,2	0,02	1,3	—	—	—	0

Habitation by depths in m	Isopoda	Pantopoda	Asteroidea	Ophiuroidea	Echinoidea	Holothurioidea	Crinoidea	Pogonophora	On the average (of the total number of species in the 16 named groups
Deeper than 3000	4,8	6,5	9,5	5,3	5,5	13,0	3,1	79,0	3,5
4000	2,4	3,8	3,0	2,3	1,8	9,1	2,0	42,1	2,0
5000	2,0	1,0	1,4	0,5	0,7	3,7	0,6	34,2	0,9
6000	1,4	0,5	0,4	0,3	0,2	1,7	0,3	29,0	0,5
7000	0,6	0	0,1	0,05	0,1	1,4	0,3	26,0	0,3
8000	0,2	—	0	0	0	0,8	0,3	26,0	0,2
9000	0,05	—	—	—	—	0,3	0,2	18,4	0,07
10000	0	—	—	—	—	0,1	0	0	0,02

seen from the tables, the number of species of all large systematic groups (types, classes, and in several cases orders) of which we have at our disposal corresponding data, diminish regularly and rapidly as the depth increases, but this impoverishment is expressed in various degrees for different groups. Polychaeta, Holothurioidea, and Asteroidea are characterized by highest absolute indicators of the number of species at depths of more than 3000 m. Ophiuroidea, crustacean Isopoda, , sea urchins, Actiniaria, and Bryozoa are also represented by a considerable number at these depths.

However, at depths exceeding the depth of the World Ocean bed, clearly predominant above all other groups with respect to abundance of species are only Polychaeta and crustacean Amphipoda. According to the abundance of species at these great depths, Holothuroidea occupy the third place and are followed by Amphipoda and Pogonophora. And finally, only individual representatives of relatively few groups of bottom animals descend to the maximum depths of ocean trenches (9000 m and more).

Pogonophora, which are basically deep-sea animals, stand out sharply among all bottom animals. About 80 per cent of species of Pogonophora inhabit depths exceeding 3000, and almost 30 per cent inhabit the greatest depths of ocean trenches, exceeding 6000 m. Up to this time only 21 per cent of Pogonophora species have been encountered.

cessed, predominantly those from maximum depths (exceeding 6000 m). The data given in Table 6 are therefore somewhat exaggerated, which pertains primarily to depths from 3000 to 6000 m.

ed at depths of less than 1000 m. Among the remaining groups, Echiuroidea, about 10 per cent of whose species inhabit depths exceeding 6000 m, are characterized by the highest degree of deep-sea occurrence. They are followed by Holothurioidea, about 2 per cent of which are encountered below 6000 m, and by crustacean Isopoda (1.4 per cent).

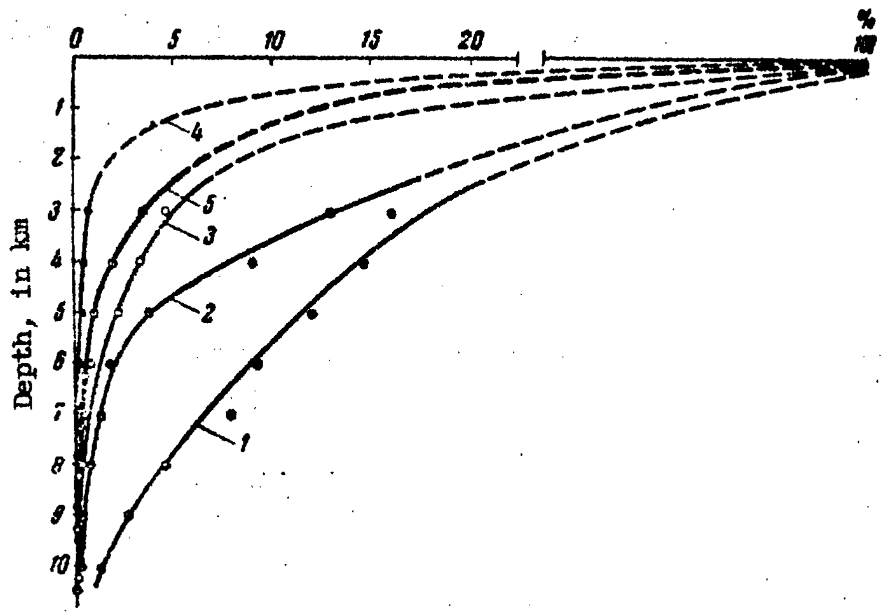

Fig. 7. Decrease in the number of species of some groups of marine bottom invertebrates with respect to the increae in depth (in per cent of the total number of species).

1) Echiuroidea; 2) Holothurioidea; 3) Actiniaria; 4) Amphipoda; 5) Summary data for 16 various groups of bottom invertebrates.

The percentage of species penetrating depths of more than 6000 m does not exceed one per cent for all the remaining groups of bottom animals. It is significant that representatives of all the four above mentioned groups penetrate to maximum depths of the order of 10000 m.

Figure 7 shows curves characterizing the decrease of the number

of species as the depth increases for certain groups of bottom invertebrates, and the central curve for 16 groups, data on which are given in Tables 6 and 7. As can be seen from this figure and from Table 7, the percentage of penetration of the bottom fauna to great depths is for all of the groups on the average small: only 3.5 per cent of all species descend to depths exceeding 3000 m, and only 0.5 per cent of species are found at depths of more than 6000 m in the deep-sea ocean trenches. Such low average indicators are stipulated by the fact that groups having the largest number of species (Amphipoda, Polychaeta, Bryozoa, and Hydroidea) are characterized by the lowest degree of occurrence in the deep sea (on the average, 1.5 per cent of species below 3000 m and 0.25 per cent below 6000 m. The highest degree of deep-sea occurrence belongs to groups having the smallest number of species (Pogonophora and Echiuroidea).

The observed regularity expresses the character of the change in the abundance of species with respect to depth in a most general way. A detailed examination of the vertical distribution of various systematic groups of bottom invertebrates by different levels permits of discovering some other peculiarities.

M. G. Vinogradova /13, 14/ pointed out that the decrease with depths of the number of species of a given group proceeds usually irregularly. There are zones of a faster and slower decrease and even of a certain increase in the number of species. Thus, for example, the number of Coelenterata which occur at depths of 2500--3000 m and more is larger that at the superincumbent level of 2000--2500 m.

A certain increase in the number of species of a score of Coelenterata groups is observed also at depths of 4000---5000 m. Similar maximums in the process of fluctuation of the total number of species at the same levels are characteristic also for sponges, Asteroidea, Holothurioidea, and a number of other groups. Such maximums are especially clearly defined for certain specifically deep-sea groups of a lower taxonomic rank (genera, families, and sometimes orders). Thus, on the basis of analysis of the vertical distribution of Holothurioidea of the Elasipoda order in the Atlantic Ocean, Ekman /50/ records an increase in the number of species of this group at depths of 2000---3000 and 4000--5000 m. Ekman cites very interesting data on the degree of deep-sea occurrence of this group: 92 per cent of Elasipoda species dwell below 1000 m, and 80 per cent below 2000 m. As Vinogradova /13/ points out, the depths where the increase in the number of species is observed correspond to zones of the strongest change in the fauna, i. e., to zones where a large number of new deep-sea species of bottom invertebrates emerge and the species fixed to lesser depths disappear.

Summarized in Table 8 are the data on maximum depths of habitation of most of the larger groups of bottom invertebrates. As can be seen from this table, representatives of a huge majority of groups inhabit depths which were only until recently considered lifeless, while members of ten groups dwell even at maximum depths of ocean trenches, at 9000 m and more. It is of interest to note that maximum depths of habitation for all groups enumerateded in Table 8 were es-

Table 8

Maximum depth of occurrence of representative of various groups of bottom animals

Group	Depth in m	Deep-sea trench	Expedition
Foraminifera	9700	Kurile-Kamchatka	"Vityaz'"
Spongia	8610	"	"
Hydrozoa	8210	Kermadek	"Galathea"
Scyphozoa	6860	Kurile-Kamchatka	"Vityaz'"
Octocorallia	8610	"	"
Hexacorallia	10190	Philippines	"Galathea"
Nematodes	4510*	Kermadek	"
Nemertini	7210	Kurile-Kamchatka	"Vityaz'"
Priapuloidea	7210	"	"
Sipunculoidea	8210	Kermadek	"Galathea"
Echiuroidea	10190	Philippines	"
Polychaeta	10190	"	"
Solenogastres	4850	Kurile-Kamchatka	"Vityaz'"
Loricata	5610	Ryu-Kyu	"
Scaphopoda	6930	Javan	"Galathea"
Gastropoda	9000	Kurile-Kamchatka	"Vityaz'"
Bivalvia	10190	Philippines	"Galathea"
Cephalopoda Octopoda	8100	Kurile-Kamchatka	"Vityaz'"
Ostracoda	5850	Kermadek	"Galathea"
Cirripedia	6960	"	"
Isopoda	9770	Philippines	"
Amphipoda	9770	"	"
Tanaidacea	8210	Kermadek	"
Cumacea	7286	Aleutian	"Vityaz'"
Decapoda	7300	Kermadek	"Galathea"
Pantopoda	6860	Kurile-Kamchatka	"Vityaz'"
Bryozoa	5850	Kermadek	"Galathea"
Asteroidea	7584*	Marianas	"Vityaz'"
Ophiuroidea	7286	Aleutian	"
Echinoidea	7250	Banda Sea	"Galathea"
Holothurioidea	10190	Philippines	"
Crinoidea	9715	Idzu-Bonin	"Vityaz'"
Pogonophora	9700	Kurile-Kamchatka	"
Enteropneusta	8100	"	"
Ascidiae	7210	"	"
Pisces	7210	"	"

* The original indications concerning the finding by the "Galathea" of Nematoda at a depth of 6620 m, of Decapoda at 6960 m, and of Aster-

tablished only during the recent years through work of the "Galathea" and "Vityaz'" expeditions, which clearly illustrates the accomplishments of the last decade in the field of deep-sea explorations.

The data on vertical distribution of bottom animals in the Kurilo-Kamchatka Trench, which has been studied in greater detail than any other deep-sea trench, are given in the article by L. A. Zenkevich, Ya. A. Birshteyn, and G. M. Belyayev /27/. These authors made a comparison of the relative content of the biomass in individual systematic groups in terms of percentage of the whole fauna at various depths in this trench (Fig. 8). It is evident from Figure 8 that the relation p of the biomass of various groups changes with respect to depth (a sharp decrese in the importance of sponges at depths between 1000 and 2500 m, the predominant role of Holothurioidea at depths exceeding 7000 m, etc.). The most abrupt change of the percentile relationship of various groups (by weight) is set at levels of 1000--2500, around 5000, and between 7000--8500 m. The examination of the vertical distribution of the bottom fauna in the Kuril.-Kamchat. Trench from various viewpoints permitted the authors to define several levels

~~oidea at~~ 7630 m /45/, utilized in the work of L. A. Zenkevich, Ya. A. Birshteyn, and G. M. Belyayev /27/, proved to be erroneous, inasmuch as articles devoted to processing of material of the "Galathea" on these groups indicate the maximum depths of occurrence of Nematoda and of Asteroidea as 4510--4570 m /80/ and 6930--7000 m /64/, respectively. The depth of occurrence of Decapoda has been corrected according to a personal message of Prof. A. Bruun.

each level being characterized by its own bottom fauna, specific for it to a certain extent. A detailed examination of the schemes of vertical zonation of the World Ocean, proposed by various authors, is given in the article by M. G. Vinogradova, Ya. Birshteyn, and M. E. Vinogradov /15/, which is published in this collection. Here one should only note that the investigation of fauna of the Kurile-Kamchatka Trench permitted to expose the specificity of fauna of the greatest ocean depths; as a result of this, L. A. Zenkevich /23/ proposed the term "ultraoceanic" for depths exceeding 6000 m, and the term "Ultra-deep-sea" for the fauna inhabiting these depths. The term "ultraabyss" and "ultraabyssal fauna" (for depths of more than 6000 m), proposed by Ya. A. Birshteyn, were employed in subsequent works of L. A. Zenkevich, Ya. A. Birshteyn, and G. M. Belyayev /26, 27/. In 1956 A. Bruun came on the basis of comparison of data obtained for a score of deep-sea trenches by the "Galathea" to an analogous conclusion concerning the specificity of fauna at greatest depths of ocean trenches, and proposed the term "hadal" for depths exceeding 6000 m.

Ultraabyssal Fauna

The systematic composition of fauna of maximum ocean depths has as yet not been completely investigated. As has been pointed out previously, the results of processing of collections made by the "Galathea" are published only partially, while the published results of the "Vityaz'" collections are even less complete, and the fully processed and published collections of the Swedish "Albatross II" in the Puerto Rico Trench are very meager and represent a small number of species.

Notwithstanding the impossibility to offer a general characteristics of the composition and geographic distribution of the ultraabyssal fauna on the basis of materials published up to the present time, a summary of the available data is still of a certain interest, since it permits of stressing the important peculiarities of the population of maximum ocean depths.

It has been shown in the preceding chapter that in the ultraabyssal zone, i. e., deeper than 6000 m, almost all groups of bottom animals, except Solenogastres, Loricata, Ostracoda, Brachiopoda, and Bryozoa, are encountered. Data on systematic composition are published only Foraminifera /42/, Hydrozoa /62/, Actiniaria /48/, Octocorallia /65/, Echiuroidea /24/, Polychaeta /38, 39, 40, 51, 59/, Mysidacea /11/, Isopoda /8. 69. 81/, Tanaidacea /82/, Amphipoda /73/, Pantopoda /35, 53, 54/, Crinoidea /55/, Asteroidea /64/, Ophiuroidea Echinoidea /64/, Holothurioidea /56, 63/, Pogonophora /29/ 30/, and Pisces /4/.

Foraminifera. Z. G. Shchedrina notes that the Foraminifera fauna at depths of more than 8000 m in the Kurilo-Kamchatka Trench "is characterized by a sharply expressed singularity of species content." Altogether 12 species were found at these depths, out of which 3 are met also at lesser depths.

Hydrozoa. Three species are given for the Kermadek Trench, including two new species.

Actiniaria. Six new species from Philippine , Java , Banda Sea, and Kermadek Trenches are described, two out of which are segregated into a new genus and a new family, and one into a new genus.

Octocorallia. Only one Umbellula coral, whose species has not been identified, is known in the Kermadec Trench.

Echiuroidea. Five new species and two new genera have been described for the Kurile-Kamchatka, Aleutian, And Idzu-Bonin Trenches. Out of these five species only one is encountered at depths of less than 6000 m.

Polychaeta. Indicated for the Puerto Rican Trench are Macellicephala sp. and Terebellidae gen. sp., not identified as to species; nine species, including five new and two unidentified species, for the Kurile-Kamchatka Trench; and fifteen species, including three new and three unidentified species, for the Philippine, Java, Banda Sea, and Kermadek Trenches.

Mysidacea. The only bottom ultra-abyssal species, Amblyops magna, has been described for the Kurile-Kamchatka Trench.

Isopoda. A new genus and species Bathyopsurus nybelini has been described for the Puerto Rican Trench; twelve species, including nine new species, for the Philippine, Banda Sea, and Kermadec Trenches; six new species and one new subspecies of the genus Storthyngura for the Kurile-Kamchatka, Japan, and Aleutian Trenches (the remaining genera have not yet been processed).

Tanaidacea. Three species are known in the Kermadek Trench, one out of which has been segregated into a special genus Herpotanais, one represents a new species of the genus Apseudes, and one has been described as a subspecies of the Neotanais serratispinosus species, found previously in the northern Atlantic.

Amphipoda. According to data of E. Dal', quoted in Wolff's work, in the trenches explored by the "Galathea" 16 species of bottom lateral-swimmers were discovered, nine out which do not rise above 6000 m. Four species are indicated for the Puerto Rican ultraabyss, but two of these are pelagic. One of the two bottom species is new. Amphipoda are numerous and heterogenuous in the trenches of the north-western part of the Pacific Ocean, but their processing has not yet been completed. Among the material processed up to this time not only new species, but new genera as well have deen found.

Pentopoda. Two species, Nymphon femorale Fage in the Banda Sea Trench and N. profundum Hilton in the Kurile-Kamchatka Trench, are known at depths of more than 6000 m. The first species has not been encountered at depths of less than 4040 m, and the second at depths of less than 3250 m.

Crinoidea. Bathycrinus australis (Clark), previously found in the Antarctic at a depth of 5650 m, is known in the Kermadek Trench. Representatives of the same genus, not identified as to species, have been collected in the Kurile-Kamchatka Trench.

Asteroidea. Two new species have been described for the Kermadc Trench. In addition, a very widespread deep-sea species, Eremicaster vicinus (Ludwig), has been discovered in the Kermadek and Java Trenches.[1]

1 Judging by Madsen's /64/ description, the species discovered in the Kermadec and Javan Trenches at depths of 6620 and 6930—7000 m is a typical Eremicaster vicinus (Lugwig). However, Madsen de-

Ophiuroidea. One very widespread species, Ophiura loveni (Lyman) is known in the Kermadec Trench.

Echinoidea. Only a single species, possibly identical with the previously known eurybathic species Pourtalesia sp.? aurorae Koeler in the Antarctic, has been discovered in the Kermadek Trench.

Holothurioidea. Holothurioidea of the ultraabyss are represented by a large number of species. Five in the Philippine Trench, three in the New Britain Trench, four in the Kermadek Trench, two in the Puerto Rico Trench (not identified as to species), Of the 13 identified ultraabyssal species, five are new and are not found at depths of less than 6000 m. Out of these one species has been segregated into a special genus Hadalothuria.

Pogonophora. Two new genera and five species have described for the Kurile-Kamchatka Trench, and one new species for the Japan Trench /30/. Only two of these six species have been found at depths

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scribes it under the name of E. pacificus (Ludwig), considering E. vicinus not to be an independent species, and including it into the synonymy of E. pacificus. According to data of G. M. Belyayev, who is processing deep-sea Asteroidea from the "Vityaz'" collection, they contain numerous representatives of both species, which have a fully independent importance and which differ substantially both morphologically and by their vertical distribution. E. pacificus is known at depths of 1570 to 4080 m, while E. vicinus is one of most deep-sea Asteroidea and is not encountered at depths of less than 5000 m.

of less than 6000 m. Besides, five additional representatives of Pogonophora, not yet identified but apparently belonging to new species, have been discovered in the Kurile-Kamchatka Trench.

A total of 11 species, belonging to 7 genera, have been thus observed at depths exceeding 6000 m.

Table 9

Total number of deep-sea animal species of the ultraabyssal zone the number of species endemic to it

Group	Total number of species	Total number of endemic species	Per cent of endemic species
F[illegible]ainifera	12	9	75
H[illegible]rozoa	3	2	66
Actiniaria	6	6	100
Octocorallia	1	?	?
Echiuroidea	5	4	80
Polychaeta	21	8	40
Mysidacea	1	1	100
Isopoda	19	16	84
Tanaidacea	3	2	67
Amphipoda	18	10	56
Pantopoda	2	0	0
Crinoidea	1	0	0
Asteroidea	3	2	66
Ophiuroidea	1	0	0
Holothurioidea	13	5	29
Pogonophora	11	9	82
Pisces	1	1	100
Total	121	75	62

Pisces. Corepractus (Pseudoliparis) amblystomopsis Andr. form the Kurile-Kamchatka Trench, segregated into a special subgenus, may be considered as the only species of ultraabyssal bottom fishes. Another fish of the genus Bassogig[illegible]s was caught during sweeping in the Javan Trench at a depth of 7130 m, but there is no certainty that this fish

was caught in the water column at a lesser depth while raising the trawl /4/.

In order to judge about the independence of the ultraabyssal fauna, it is interesting to compare the number of species fixed to the ultraabyssal zone only with the number of all species encountered in this zone. Wolff made a similar comparison, but our Table 9 utilized more complete data set forth above.

Thus, on the average 60 per cent of bottom animals found at depths exceeding 6000 m are represented by species not encountered at lesser depths, which may serve as a sufficient ground for independence of the ultraabyssal fauna. This independence is stressed by the existence in the ultraabyss not only of species fixed to it, but of higher taxonomic units, of genera and even of families, as well. Among Actiniaria a new ultraabyssal family, Galatheanthemidae, and two new genera, Galatheanthemum and Hadalanthus, have been discovered; among Polychaeta, the genera Vitjazia and Macellicephaloides; among Echiuroidea, the genera Jacobia and Vitjazema; among Amphipoda, the genus Artyrolais (not yet published); among Isopoda, the genus Bathyopsurus; among Holothurioidea, the genus Hadalothuria; among Pogonophora, the genera Heptabrachia and Zenkevitchiana; among fishes, the subgenus Pseudoliparis. A similar phenomenon is common to the plankton of the ultraabyssal zone, whose composition is known to contain a special Amphipoda family Vitjazianidae /9/ and two ultraabyssal genera of Calanoida, Parascaphocalanus and Zenkevitchiella /12/, not counting a significant number of special ultraabyssal species.

As Zenkevich, Birshteyn, and Belyayev /26, 27/ had assumed, and as it is now being confirmed by factual material, the fixation of most species making up this specific ultraabyssal fauna to any single isolated ocean trench should be regarded as its remarkable property. Consequently, each trench is characterized by an ultraabyssal fauna endemic to it.

Thus, for example, each of the six ultraabyssal species of Actiniaria and of the nine ultraabyssal species of Isopoda, collected by the "Galathea, has been detected only in one of the several trenches. The case of Holothurioidea and Polychaeta is somewhat different. Of the five new ultraabyssal species of Holothurioidea, one (Myriotrochus bruuni) has been found in two trenches, the Philippines and the New Britain. Of the three new species of Polychaeta, one (Macellicephala hadalis) occurred in the Kermadek, Banda Sea, and Philippines Trenches. The two named species represent in this respect an exception to the whole mass of ultraabyssal species, and the fact that they were found in two trenches very distant from each other and sepparated by large extents of the ocean bed only 3000--5000 m deep needs additional explanations.

The narrow endemism of the specifically ultraabyssal species is exemplified also in the fauna of ocean trenches in the western Pacific Ocean, which were explored by the "Vityaz'." However, this phenomenon is complicated by various degrees of isolation of the explored trenches. The Kurile-Kamchatka, Japan, and Izu-Bonin Trenches are interconnected by depths of the order of 6000 m, so that only

their maximum depths are isolated. The Aleutian Trench is isolated from other trenches by a substantial area of the ocean bed, whose usual depths amount to 4000--5000 m.

In conformance with this, a number of ultraabyssal species, particularly the Isopoda Storthyngura vitjazi, St. chelata, St. herculea, the Echiuroideum Vitjazema ultraabyssalis, and the fish Careproctus amblystomopsis, are common both to the Kurile-Kamchatka and the Japan Trenches. The ultraabyssal pelagic Gammaridea are also distributed, without gaps, from the Kurile-Kamchatka Trench in the north to the Japan and even to the Izu-Bonin Trench in the south /10/.

Along with this, certain differences in the systematic location of ultraabyssal species are observed between the completely isolated Kurile-Kamchatskaya and the Aleutian Trenches. Thus, for example, the Echiuroidea genus Vitjazema is represented in the Kurile-Kamchatka Trench by the species V. ultraabyssalis, and in the Aleutian Trench by the species V. aleutica /24/, and the Isopodum Storthyngura tenuispinis from the Aleutian Trench is represented in the Kurile-Kamchatka Trench by a special subspecies, and possibly a species, S. camtschatica /8/.

Indications exist concerning the heterogeneity of populations obtained form maximum depths of the Kurile-Kamchatka and Japan Trenches, notwithstanding that they are connected by a gut about 6000 m deep. Representatives of the most deep-sea (7200--8280 m) species of the Storthyngura genus, S. vitjazi, from the above named trenches are morphologically different, which may be regarded as the emergence of in-

itial stages of divergence /8/.

Apart form representatives of the specific ultraabyssal fauna which do not rise to depths of less than 5000--6000 m and which are characterized by a clearly expressed narrow endemism, a significant number of variously eurybathic species, enccountered also in shallower vertical zones up to the upper sublittoral, were detecred within the limits of the ultraabyssal zone.

The Polychaeta Ancistosyllis constricta Southern, known from the Indian brackish-water lake Chilka and from the depth of 6580 m in the Banda Sea Trench, and Tharyx multifilis, found at the same depth in the same trench and previously known near the California coast at a depth of 1 to 590 m, in the Persian Gulf at depths of 8--110 m, and near the Vancouver Islands at the depth of 70 m /59/, may be considered as amazing examples of extreme eurybathicity and of eurybionthicity in general. The hydroid Aglaophenia tenuissima Bale was found in the Kermadec Trench at a depth of 6660--6720 m, and in the waters of the Great Australian Barrier Reef at the depth of 293 m /62/. The Holothuricideum Mesothuria murrayi Théel was discovered in the Banda Sea Trench at depths of 6490--6550 m, and was encountered in the Indonesian waters and in the Pacific Ocean at depths of 254--560 m. The Echiuroidum Alomasoma nordpacifica Zenk. dwells in the north-western part of the Pacific Ocean at depths from 520 to 7820 m /24/, the Isopodum Ilyarachana antarctica Vanh. is known from depths of 252 and 7000 m /81/. The Pogonophorum Siboglinum caullerui Ivanov, found in the Kurile-Kamchatka Trench at the depth of 8100 m, is common in the Sea of

Okhotsk at depths from 23 to 3400 m /30/.

Even a larger number of species appears to be common to the lower levels of the bathyal, abyss, and ultraabyss. Among the Polychaeta this is Macellicephala abyssicola Fauvel (4225--7290 m), Nephtys Elamellata Eliason (4255--7000 m), Ninoe fusca Moore (4063--7000 m), Ilyphagus bythinicola Chamberlin (3436--6740 m), Travisia profundi Chamb. (975--7290 m), etc.; among the Isopoda, Storthyngura pulchra (Hansen) (1260--6620 m) and Eurycope nodifrons Hansen (2702--7000 m); among Crinoidea, Bathycrinus australis (Clark) (3650--8300 m); among Asteroidea, Eremicaster vicinus (Ludwig) (5000--7000 m); among Ophiuroidea, Ophiura loveni (Lyman) (2500--6720 m); among Holothurioidea, Peniagone naresi (Théel) (3292--7160 m), Scotoplanes globosa (Théel) (3564--6720 m), Benthodytes sanguinolenta Théel (768--7290 m), Euphronides verrucosa Ludwig (2404--7290 m), Pseudostichopus villosus Théel (896--7290 m), and Caroplectana trachyderma Clark (388--6650 m).

A special place in this series is occupied by the Holothurioideum Elpidia glacialis (Théel). Very widespread in the Polar Basin at depths from 70 to 3800 m and considered usually as a high-arctic species, it was found in the Atlantic Ocean near the shores of Morocco at a depth of 2210--2480 m and south of Australia at a depth of 4750 m, and in the recent years was discovered in the Strait of Kamchatka at a depth of 4400 m /5/, near Antarctica at a depth of 2980 m (the first "Ob'" expedition), and in large numbers in the ultraabyss of many trenches (Kurile-Kamchatka, Aleutian, Japan, Kermadec, Java, and Bougainville (New Britain)). According to Hans-

en /56/, a special subspecies, easily distinguished from the typical subspecies fixed for the Arctic and the northern Atlantic, inhabits each of the three latter trenches. The emergence of different subspecies of E. glacialis in various trenches reminds of a similar process common to true ultraabyssal constituents, and permits of assuming that E. glacialis were established in various trenches a long time ago.

The scheme, proposed by Kirkegaard /59/ for ultraabyssal Polychaete, can be employed for ecological demarcation of heterogenous members of the bottom population of the ultraabyssal zone. This author distinguishes three following groups: 1) eurybathic and eurythermic species, having probably a universal distribution, 2) eurybathic and stenothermic species, having a wide distribution, but living at a temperature of 4°C, 3) stenobathic and stenothermic species, making up the true "hadal," i. e., ultraabyssal, fauna.

The development of the problem of the origin of ultraabyssal fauna is hindered by the fact that it has not been extensively studied, and opinions expressed in this respect represent insufficiently well based hypotheses. Bruun /47/ assumes that the abyss and ultraabyss have been populated relatively recently by migrants from the bathyal and sublittoral. On the basis of investigations of subfossilized abyssal Foraminifera, he admits the possibility of a considerable drop in the temperature of deep-sea water during the great glaciation, which caused the extinction of all pre-quarternary abyssal fauna, with the exception of its most eurythermic individual representatives which are preserved up to this time in the form of relics. Later on a part of

bathyal and to some extent of sublittoral species adapted to life in the depths of abyss and even of ultraabyss. The cold-loving inhabitants of the Arctic and the Antarctic migrated thus most easily. Bruun points out the substantial number of primitive archaic species in the composition of bathyal fauna (e. g., Latimeria), and considers the presence of similar species in the abyss and ultraabyss the result of their secondary migration to greater depths.

Wolff expresses similar views with respect to ultraabyssal crustacean Isopoda. He establishes a closeness of most endemic ultraabyssal species with inhabitants of the ocean bed in the vicinity of trenches populated by them, which confirms the possibility of their recent settling in the trenches. The majority of crustacean Isopoda are actually related to Antarctic and Arctic species, which conforms to Bruun's views expressed immediately above.

These presentations are not confirmed by the available paleoclimatological data, according to which no sufficient bases exist for recognition of strong changes in the temperature of deep-sea water masses during the quarternary period. Nevertheless, the presence of recent settlers at great ocean depths, which are in addition populated by earlier deep-sea inhabitants, causes no doubts. This circumstance was first noted by A. P. Andriyashev /1, 3/, who distinguished in the composition of deep-sea fish fauna "ancient or true deep-sea species," pertaining to lower philogenetic groups and deeply specialized for conditions of life at depths, and secondary deep-sea species," weakly differentiated systematically from the inhabitants of the continental

shelf, and belonging to philogenetically young groups.

It should be noted that such secondary deep-sea species descend in a number of cases to the ultraabyss, where they transform into true ultraabyssal species. Exactly such are the most deep-sea bottom fish Careproctus amblystomopsis Andr. /4/ and the most deep-sea bottom mysid Amblyops magna Birst.et Tschind. /11/.

However, judging by data available at the present time, the majority of inhabitants of the abyss and ultraabyss do not belong to the secondary deep-sea species. Their systematic place and morphologic peculiarities permit their being assigned, with a sufficient degree of certainty, to primary deep-sea species, the early inhabitants of great depths. The relic character of many abyssal groups has been emphasized by Ekman in his well-known book "Zoogeography of the Sea" /49/. Examples given by this author on the ancient geologic age of a considerable part of inhabitants of the abyss may be supplemented by data on crustacean Decapoda by the well-known paleontologist Beurlen /43/.

Comparing the systematic composition of fossil and deep-sea crustacean Decapoda, Beurlen arrived at the conclusion that these animals settled at great depths predominantly in the Upper Jurassic, Upper Cretaceous, and Upper Eocene periods.

Sufficient reasons thus exist to recognize the early settlement of the abyss and the antiquity of a substantial part of its peculiar fauna. As applied to the ultraabyss, this question must be put in a different manner. According to V. V. Belousov /6/, island arcs and the accompanying trenches represent a structure of the Alpine age.

In this case, the settlement of the ultraabyssal zone could have begun only from the Tertiary period on. In harmony with this is the closeness of many ultraabyssal species, for example, of crustacean Isopods /8, 81/, to abyssal and partially even to bathyal species; these species did not succeed in significantly differentiating from their more shallow-water ancestors. However, as has been indicated previously, the ultraabyssal zone is inhabited not only by special species common to it, but by special genera and even families as well. The origin of these species of high taxonomic rank is enigmatic, since the possibility of their emergence during the brief period of existence of deep ocean trenches is highly doubtful.

<u>Quantitative Distribution of Deep-sea Bottom Fauna</u>

The development of a general presentation of the quantitative distribution of living organisms in the World Ocean is of a great theoretical interest and has a substantial practical importance. Generalized schemes of distribution of the population density in the World Ocean, pertaining, to be true, primarily to the population of the pelagic zone, were proposed by Hentschel /58/, L. A. Zenkevich /21/, and Sverdrup /78/. According to these schemes, the greatest density is observed, on one hand, in the near-polar regions of the oceans, and on the other, in the immediate vicinity of mainland shores, within limits of the continental shelf.

With respect to the quantitative abundance and distribution of bottom fauna in the coastal shallows and in the open parts of epicontinental seas, we possess at this time rather considerable data, ob-

tained for various regions. Studied in greatest detail in this respect are the Danish waters, the Barents, Karskoye, and White Seas, certain regions of our Far-Eastern seas, the Black, Caspian, and Aral Seas, and the Sea of Azov. A number of other regions, particularly some parts of the Mediterranean have been explored with lesser detail.

The data on quantitative distribution of bottom fauna at depths of about 1000 m and more were up to recent times practically absent. Only the expedition "Persey" of the State Oceanographic Institute collected in 1931 two dredging samples from depths of 800 and 1000 m in the Greenland Sea west of the Medvezhiy Island, and in 1947 two dredging samples were taken in the same region at depths of 900 and 2000 m by the expedition vessel "Kashalot" of the Polar Marine Institute for Fisheries and Oceanography. The biomass of benthos at these depths equalled from 1.3 to 2.0 g/m^2 /20/.

Broad quantitative explorations of the deep-sea bottom fauna of the World Ocean were made by the "Galathea" in 1950--1952, by the "Vityaz'" in 1949--1955, and by the "Ob'" in 1956.

The "Galathea" expedition collected in various regions 60 quantitative dredging samples from depths of 1000 to 6000 m, and 5 samples from depths exceeding 6000 /76/. Two samples, taken in the Banda Sea by the 0.2 m^2 grab from depths of 6580 and 7280 m, contained 12 and 7 animal specimens, respectively, weighing 2.5 and 0.7 g, which yields for such depths rather high biomass indicators of 12.5 and 3.5 g/m^2. The sample taken from the greatest depth (Philippines Trench,

10120 m) contained only one Holothurioideum weighing 0.1 g, which corresponds to a biomass of 0.5 g/m² /77/.

Spärck /75/ quotes very interesting data on deep-sea quantitative investigations of the "Galathea" near the western shores of Equatorial Africa (Gold Coast, Congo, Angola). In these regions, 13 dredging samples were taken from depths of 820—3782 m. Corresponding data on biomass indicators are summarized in Table 10. It is characteristic that the bottom fauna in this part of the Atlantic Ocean, at depths of less than 4000 m, proved to be quantitatively much poorer than in the Banda Sea at depths exceeding 6000 and even 7000 m. Factual data pertaining to the remaining dredging samples taken by the "Galathea" are not yet published.

Table 10

Biomass of deep-sea benthos near western shores of Equatorial Africa

Depth in m	Biomass in g/m²		Number of samples
	Range of fluctuations	Average	
820—1008	1,0—4,5	3,0	4
1150—1708	1,0—3,0	1,75	6
2430—3782	0,5—3,1	1,57	3

In addition to very numerous quantitative dredging samples from depths of less than 1000 m, the "Vityaz'" collected in the Far-Eastern seas and in the north-western part of the Pacific Ocean more than 170 such samples from depths 1000 to 7266 m (Table 2). These materials have been processed by C. B. Mokiyevskiy /52/ for the part adjoining the deep-sea regions of the Sea of Japan; his studies offer data on

indicators of biomass and of quantity, and on the systematic composition of bottom fauna in the Sea of Japan at depths of more than 1000 m. A map, showing the distribution of the total biomass of benthos in the whole area explored by the "Vityaz'," has been compiled by a group of members of the Benthos Laboratory of the Institute of Oceanography (Fig. 9) as a result of processing the material collectied by the "Vityaz';" this map was published in works of L. A. Zenkevich /23/, and of L. A. Zenkevich and Z. A. Filatova /28/. As can be seen from

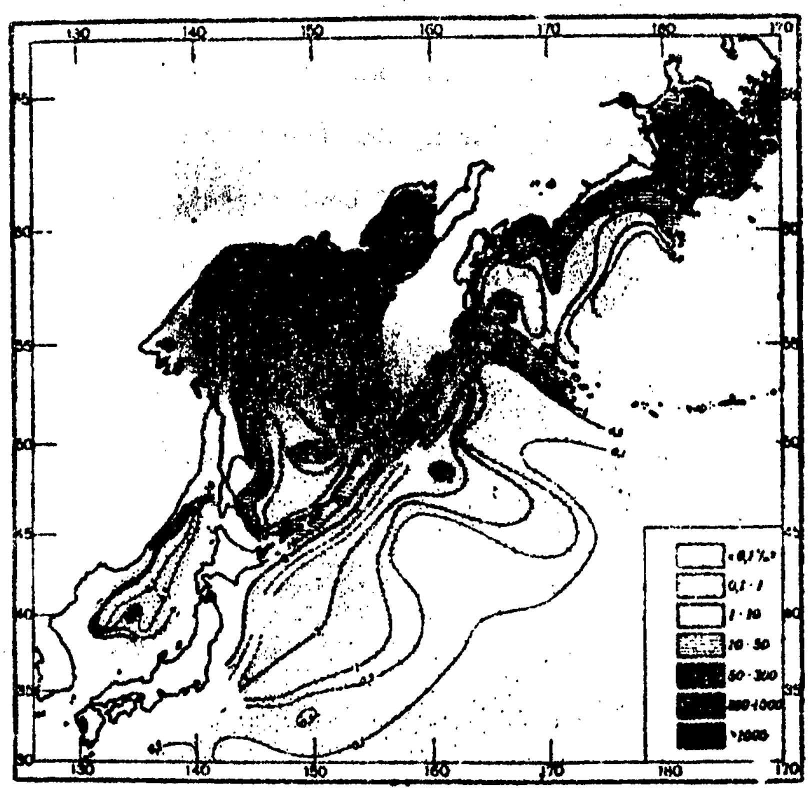

Fig. 9. Quantitative distribution of bottom fauna in the Far-Eastern seas and in the adjoining part of the Pacific Ocean (in g/m^2) /23/.

this map, the total biomass of bottom fauna in the coastal parts of the Sea of Okhotsk and of the Bering Sea, and near the Pacific shores

of the Kamchatka, reaches several hundred, and in some locations exceeds 1000 g/m^2. As one goes farther from the seaboard and as the transition from sublittoral to bathyal takes place, the biomass of benthos diminishes gradually everywhere down to several tens of g/m^2. At depths of 1000--3000 m in the Bering Sea and in the Sea of Okhotsk, the biomass of benthos decreases to 10--20 g/m^2, and in the Sea of Japan even to 1.5--7 g/m^2. In the central parts of deep-sea basins of all three Far-Eastern seas, the biomass falls down to 1 g/m^2, and in some places to 0.1--0.2 g/m^2. The only exception are certain regions of the western pan of the Bering Sea (west from the submarine ridge of Shirshov), where the biomass of benthos reaches 5 g/m^2 and more, and especially that part of this basin, which adjoins the deep-sea Kamchatka Strait. Here, at a depth of more than 4000 m, the biomass reaches 30 g/m^2, which is apparently explained by the peculiarities of the hydrologic regime in the region of the Kamchatka Strait, which favor the increase in productivity of the bottom fauna.

In the north-western part of the Pacific Ocean, a narrow strip with a biomass of benthos exceeding 10 g/m^2 stretches along the shallows bordering the Kurile island arc, the eastern coast of the Kamchatka, and the Aleutian island arc. In the direction of the open ocean, as one moves away from the coast, a gradual decrease of the biomass is observed. In the most remote regions of the explored part of the ocean (south from 23° N. Lat.), at depths of the order of 5000 m, the bottom fauna if quantitatively extremely poor and its biomass is expressed in terms of 100 mg/m^2 and less.

It is highly interesting that at depths substantially greater than those of the ocean bed, in the Kurilo-Kanchatskaya and Aleutian Trenches, the biomass of benthos is higher than at lesser depths of much remoter open parts of the ocean. Thus, for example, "Vityaz'" took in 1955 a dredging sample at a depth of 6938 m near the southern tip of Kamchatka in the Kurilo-Kamchatskaya Trench, which yielded a biomass indicator of 3.42 g/m^2. In the same year, dredging samples were taken at two stations in the Aleutian Trench, at depths of 6460 m (across from the Mednyy Island) and 7286 m (across from the Attu Island). The biomass of benthos at these stations was 0.4 g/m^2 and 0.56 g/m^2.[1] The utilization of the trawlograph during sweepings of the "Vityaž'" in the Kuril -Kamchat Trench permitted of making a quantitative estimate of collections obtained at various depths, up to the maximum /27/. These data (Table 11) also testify about the greater quantitative abundance of bottom fauna of the ultraabyssal

1 The sample from 7286 m contained 20 specimens of small Polychaeta, 2 bivalves, 1 small crustacean of the Cumacea order and 1 tiny Ophiuroideum, weighing together only 0.14 g, which corresponds to a biomass of 0.56 g/m^2. In addition, the sample disclosed 1 large Echiuroideum weighing 10.1 g. One should take into account, however, that such large organisms are collected by grabs at great depths very infrequently. A mechanical accounting for the weight of such an organism per square meter would therefore undoubtedly produce a greatly exaggerated biomass indicator, incongruent with reality.

trench rather than of the abyss of open oceanic spaces.

The solution for the relatively high indicators of bottom fauna biomass in the ultraabyss of trenches should be apparently sought in the closeness of trenches to shores and in the abundant drift of organic matter in the direction of their depths.

Table 11

Change in total biomass of benthos in the Kurile-Kamchatka Trench with respect to increase of depth, according to data of sweeping hauls

Depth in m	Biomass in g/m² Range of fluctuations	Average	Number of sweeping hauls
950–4070	3,45—14,88	6,94	4
5070—7230	0,68—2,47	1,22	4
8330—9950	0,05—0,93	0,32	4

It is necessary to note that the biomass indicators obtained according to sweeping hauls as well as according to dredging samples for great depths should be considered somewhat reduced, since the trawl fails to catch the smallest representatives of the deep-sea benthos, while the grab, with rare exceptions, does not seize large animals, because their colonies are at great depths very widely dispersed. In addition, one should bear in mind that no methods permitting the segregation of empty shells of Foraminifera from live specimens in the sample, and accounting for the biomass of the latter, whose role in the total biomass of deep-sea benthos is undoubtedly very significant, has as yet been developed.

The Antarctic expedition of the Academy of Sciences of the U.S.

S. R. on the "Ob'" made in 1956 deep-sea dredging collections in the waters of the Antarctic from the Davis Sea to Balleny Islands south of 64° S. Lat. (11 samples from depths of 1000—3200 m and in various regions of the Indian Ocean (9 samples from depths of 1000—4500 m). As G. M. Belyayev and P. V. Ushakov /7/ point out, indicators of the biomass of benthos fluctuate in the Antarctic waters at depths of 1000-3200 m from 0.54 to 2.8 g/m^2, and amount on the average to 1.3 g/m^2, which is several times as small as the indicators for the same depths in various other regions, particularly in the Far-Eastern seas, but only inconsiderable smaller than biomass values characteristic of similar depths near the western shores of Equatorial Africa.

Spärck /76/ points out that the value of the biomass of benthos at maximum ocean depths may be taken as being in the vicinity of 1 g/m^2. A comparison of data accumulated up to this time permits of approaching the estimate of the quantitative abundance of the bottom fauna of ocean depths in a more differentiated manner.

The most general regularity, which first of all determines the quantitative distribution of the bottom fauna from the coastal sublittoral zone to the deepest parts of the ocean, is the decrease of the total biomass of benthos with respect to increase in the depth. At greater ocean depths another factor comes into play, i. e., the remoteness from continental shores. Still in 1895 Murray /67/ noticed the great importance of the remoteness of a given part of the sea floor from the shores, which determines the supply of the bottom fauna with nutritive materials of a terrestrial or coastal origin. In t sub-

sequent years other authors /23, 49, 52/ expressed similar views in various ways, while at the present time they are fully confirmed by concrete data of quantitative explorations of the deep-sea bottom fauna.

The vast water area of the Pacific Ocean, the remoteness from continents, a substantial distribution of red clays which possess a high radioactivity, and a relatively small river discharge (large Asiatic rivers are separated from the ocean by island arcs) offer a basis for assumption that the bottom population of open areas of the Pacific Ocean will prove to be quantitatively poorer than in the Atlantic Ocean. On the other hand, we can expect precisely in the Pacific Ocean the occurrence of greatest abundance of life in maximum ocean depths, inasmuch as the majority of deep-sea trenches, situated in the immediate vicinity of continents and island arcs, are located here.

As could have been observed, the data on qualitative and quantitative distribution of the bottom fauna of the ocean bed and of deep-sea ocean trenches are still very meager. However, their value is indisputable not only with respect to characteristics of fauna of a huge and very peculiar area of the biosphere, but also with respect to characteristics of the live population of regions of great depths, under whose immediate "control" the accumulation of floor deposits takes place. Both according to its systematic composition and according to its biogeochemical and quantitative indicators, this fauna may be an important indicator of deep-sea deposits, for which we have still no reliable characteristics.

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TO BE CONTINUED

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